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Flight Service Evaluation of Kevlar-49 Epoxy Composite Panels in Wide-bodied Commercial Transport Aircraft

Eighth Annual Flight Service Report

R.H. Stone

LOCKHEED-CALIFORNIA COMPANY
BURBANK, CALIFORNIA

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Langley Research Center
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FOREWORD

This is the eighth annual flight service evaluation report on the condition of Kevlar-49 fairing panels installed on three L-1011s under NASA Contract NAS1-11621, "Flight Service Evaluation of Kevlar-49 Composite Panels in Wide-Body Commercial Transport Aircraft." This report also includes an update of results from concurrent ground-based exposure tests on Kevlar-49 coupons being conducted by NASA-Langley. The manufacture and installation of these panels was completed in February 1973 and reported in NASA CR-112250 dated March 1973 (reference 1). The results of inspections after the first seven years of flight service were reported in references 2 through 8. The original 5-year flight service program was extended for an additional 5 years through 1983. Annual reports will be issued describing service performance after each year of service through the 10-year duration of the program.

This program is being administered by the Langley Research Center, National Aeronautics and Space Administration, with Mr. Benson Dexter of the Materials Division as the project Engineer.

This program is being performed by the Lockheed-California Company with Robert H. Stone the Program Leader, assisted by personnel of the Product Support Branch.

N82-22316 #

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INTRODUCTION AND BACKGROUND

The subject program on flight service evaluation of Kevlar-49 fairings consists of fabrication, installation, and flight service evaluation of six secondary structural panels on each of three L-1011s. The three participating airlines are Eastern, TWA, and Air Canada. Fabrication and installation of the panels was completed in February 1973, with initiation of flight service occurring in early 1973 on all three aircraft.

In all of the prototype fairings Kevlar-49 fabric, comparable in fabric weave and thickness per ply to the baseline fiberglass, was substituted for the fiberglass on a ply-for-ply basis. This required no other design changes or development of new tooling for layup and cure, but still provided a savings in component mass of 25-30 percent. These six parts are as follows:

- A left-hand and right-hand set of large 152- by 170-cm (60- by 67-in.) sandwich wing-body fairing panels. The exterior skin is 0.05 cm (0.02 in.) thick with one ply of 181 style Kevlar-49 fabric and two plies of 120 style Kevlar-49 fabric. The interior skin is 0.04 cm (0.015 in.) thick with three plies of 120 style Kevlar-49 fabric. The honeycomb core is Nomex with 0.3 cm (1/8 in.) cells, and 0.05 gm/cm^3 (3.0 lb/cu ft) density. Overall panel thickness is 2.36 cm (0.93 in.), with a solid laminate edge 0.30 cm (0.12 in.) thick, built up of 181 style Kevlar-49 plies (Figure 1).

- A left-hand and right-hand set of small 14- by 83-cm (5.5- by 32.5-in.) solid laminate underwing fillet panels. The laminate incorporates nine plies of 181 style Kevlar-49 fabric and is approximately 0.23 cm (0.09 in.) thick (Figure 2).

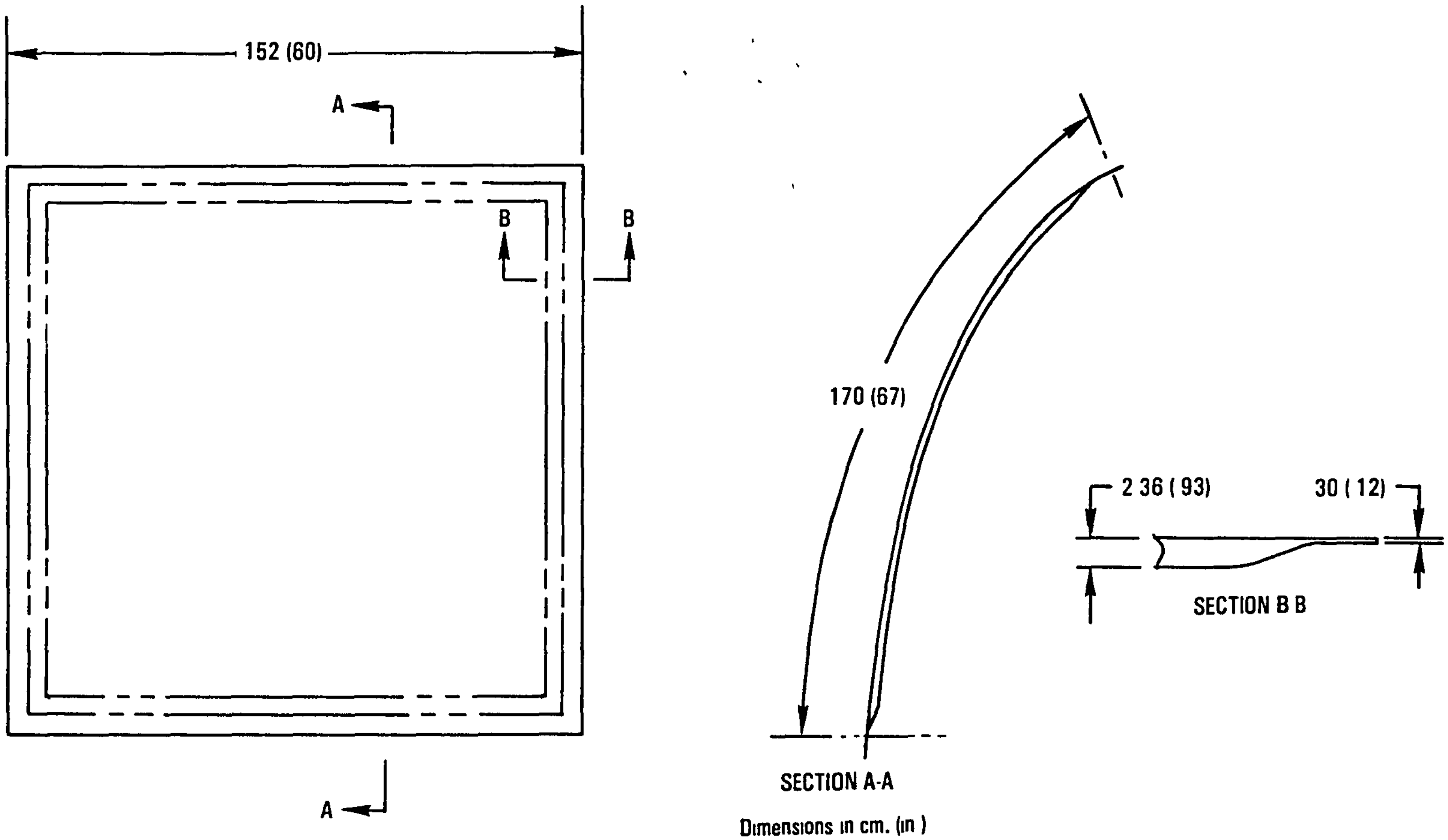

Figure 1. - Wing to Body Fairing Panel.

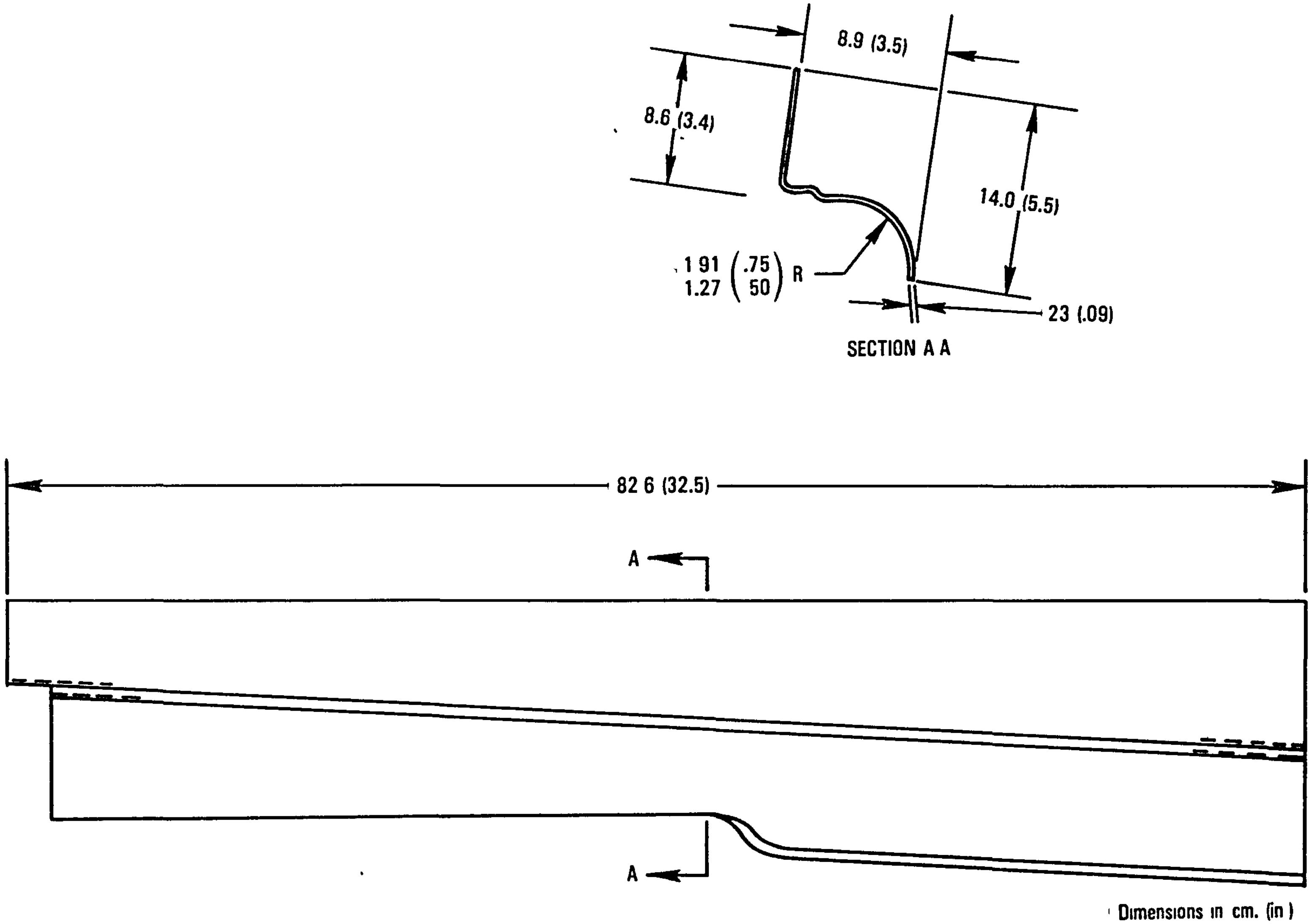

Figure 2. - Underwing Fillet Panel.

- A left-hand and right-hand set of aft engine sandwich fairings 76- by 208-cm (30- by 82-in.) approximately. The skins are 0.05 cm (0.02 in.) thick with one ply of 181 style Kevlar-49 fabric and two plies of 120 style Kevlar-49 fabric. The Nomex core is identical to that used in the wing-body fairing except for thickness, and the overall panel thickness is 0.64 cm (0.25 in.). The aft engine fairing has a solid laminate edge member 0.25 cm (0.10 in.) thick (Figure 3).

The Kevlar-49 panels used the same resin system as the production fiberglass parts. A 121°C (250°F) curing, 82°C (180°F) service epoxy (Hexcel's F-155) was used in the wing-body fairing and underwing fillet panels; and a 177°C (350°F) curing, 149°C (300°F) service epoxy (Hexcel's F-161) was used in the aft engine fairings. Two fabric weave styles of Kevlar-49 were used. The Kevlar-49 style 181 is an 8-harness satin weave similar to the 181 fiberglass weave, 0.23 mm (9 mils) per cured ply and 0.17 kg/m^2 (5.0 oz/yd^2) dry mass. Kevlar-49 style 120 is a plain weave, 0.13 mm (5 mils) per cured ply and 0.06 kg/m^2 (1.8 oz/yd^2) dry mass. Both fabric styles incorporate light denier Kevlar-49 yarns, 380 denier for style 181, and 195 denier for style 120. The heavy denier yarns used in styles 281 and 285 Kevlar-49 fabric had not been developed at the time these parts were made.

All of the parts have an outer layer of flame-sprayed aluminum and topcoat applied according to standard production procedures used on the baseline fiberglass parts. The actual savings in component mass achieved by this direct substitution of Kevlar-49 for fiberglass averaged 26 percent for the six parts. Further details on Kevlar-49 part design and fabrication are given in NASA CR-112250 (reference 1), which is the final report of the fabrication and installation phases of the program.

The first annual inspection results are given in NASA CR-132647 (reference 2). The Air Canada and TWA panels were inspected at Lockheed in this case due to special circumstances, while Eastern personnel inspected the Eastern panels at their Miami Maintenance Base.

For the second annual inspection and all subsequent inspections, the program scope was expanded as follows to obtain more complete information and documentation of part conditions:

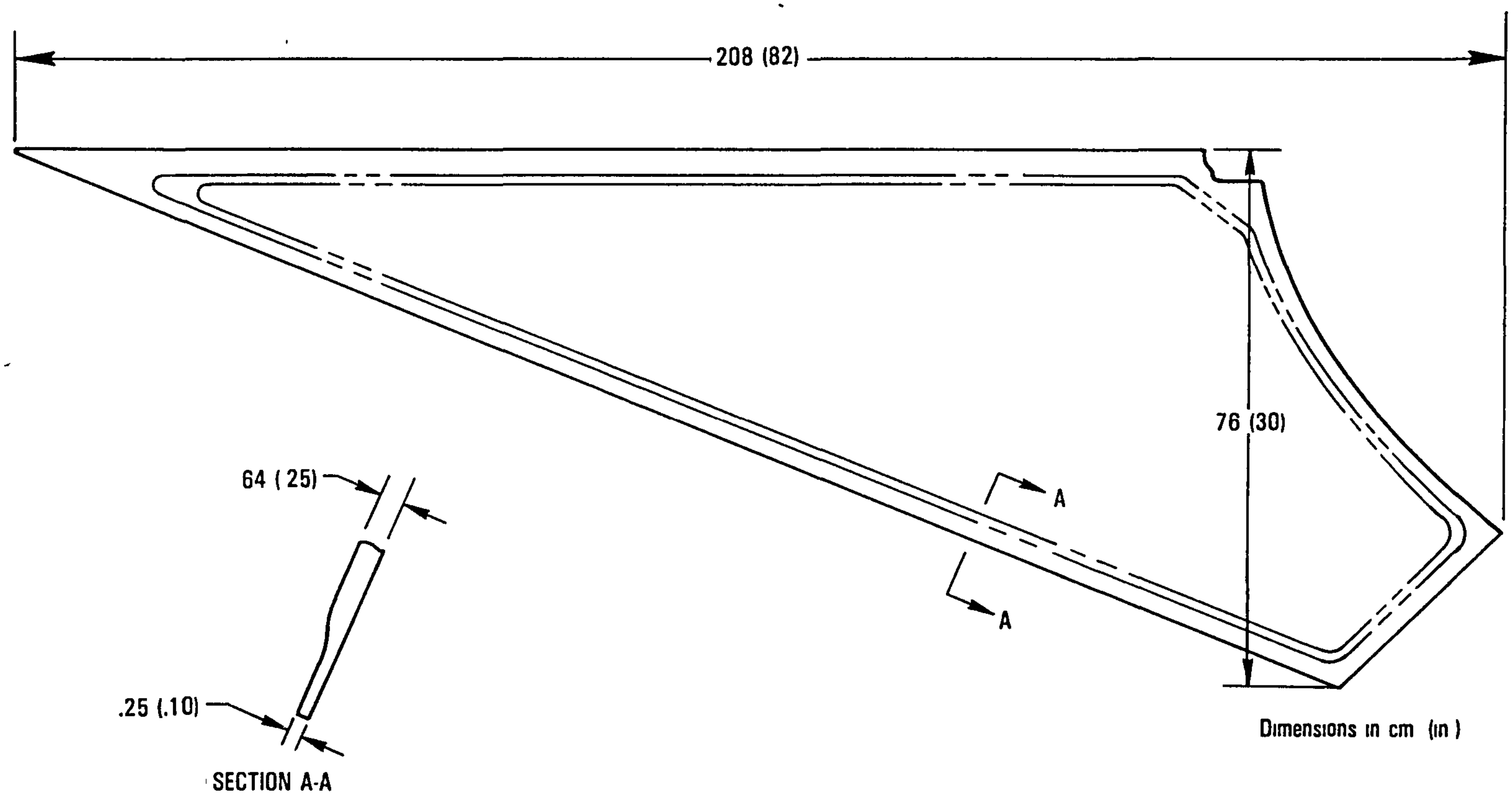

Figure 3. - Center Engine Fairing Panel.

- A Lockheed Engineering representative is present for each annual inspection at the airlines' maintenance bases.
- Three of the six panels (one of each left-hand and right-hand set) are removed for thorough inspection, weighing, and inspection of fastener holes and interior surface conditions.
- The airlines provide reports to Lockheed on all incidences of damage and repair occurring in service.

The second through the seventh annual inspections were conducted in accordance with this expanded scope, and are reported in NASA CR-132733 (reference 3), NASA CR-145141 (reference 4), NASA CR-145326 (reference 5), NASA CR-159071 (reference 6), NASA CR-159231 (reference 7), and NASA CR-165733 (reference 8).

As discussed in previous reports, the TWA panels were removed after approximately 1 year (2400 hours) of service, and reinstalled on a second TWA L-1011 for continuation of flight service testing. The reinstallation on TWA aircraft N31030 required some rework and repair of the panels, particularly in the case of the aft engine fairing panels, where relocation of all fastener holes was required. This rework activity is reported in detail in the Second Flight Service Report (reference 3). The aircraft on which these parts were installed was delivered to TWA in August 1975, and have since been inspected annually in accordance with the expanded program scope.

During 1977, a 5-year extension to the program was received from NASA for a total of 10 years flight service of the Kevlar-49 fairings. This extension carries the program through 1983, and annual inspections of the three shipsets will take place in accordance with the expanded program scope outlined above.

In 1978, Eastern disclosed plans to lease the aircraft with the Kevlar fairings to a foreign carrier, but stated a willingness to reinstall the fairings onto a second aircraft. Additional funding was received for this reinstallation. Removal of the panels took place in 1979 and was discussed in the Sixth Flight Service Report (reference 7). The panels were reinstalled onto Eastern Ship N313EA during 1980, and this activity is discussed in the Seventh Flight Service Report (reference 8).

The fairings being evaluated in this program are the earliest Kevlar-49 components placed in commercial airline flight service, predating production applications of Kevlar-49 on commercial transports by several years. These components are exposed to over 2000 flight hours per year of typical aircraft operating environments; and detailed monitoring of the fairings' performance in this program provides information on long-term durability, damage tolerance, chemical resistance, and mechanical properties. Kevlar-49 fibers are the only organic reinforcing fibers used in aircraft structures, and have certain characteristics, such as moisture pickup in the fiber and low resin/fiber bond, which were of concern initially. The resistance of Kevlar-49 composites to long-term service environment as verified by the 8 years of flight service in this program provides confidence in the use of Kevlar-49 for additional aircraft structural applications.

Concurrent with the flight service evaluation, Kevlar-49 test coupons are being subjected to long-term environmental exposures at various ground locations throughout the world, providing a variety of climatic conditions. The test coupons were fabricated using the same materials (Kevlar-49/F155 and Kevlar-49/F161) as the flight service fairings, and were fabricated at the same time and at the same facility (reference 1). The coupons are being tested at 2-year intervals for moisture weight gain and residual mechanical properties, and the results after 1-year and 3-year exposures are given in the Fourth Annual Flight Service Report (reference 5). This report includes test data after 5-year and 7-year exposures.

PANEL INSPECTIONS

The eighth annual inspection of the Air Canada fairings on Ship CF-TNB-502 (Serial No. 1021) took place on July 23, 1981 at the Montreal Maintenance Base. The right-hand wing-body fairing panel, the right-hand underwing fillet panel, and the left-hand aft engine fairing panel were removed for inspection, while the opposite set of panels were inspected on the aircraft. This was the opposite set to those removed in the previous

inspection. The fairings at the date of inspection had been in-service for eight years, and had accumulated 20,406 flight hours. In the 13-1/2 months since the previous inspection, the fairings had accumulated 2966 hours.

The inspection of the TWA fairings on Ship N31030 (Serial No. 1111) took place at TWA's Los Angeles Maintenance Base on September 19, 1981. The left-hand wing-body fairing panel, the right-hand underwing fillet panel, and the right-hand aft engine fairing panel were removed for inspection, while the opposite set of panels were inspected on the aircraft. These were the opposite parts to the wing-body and aft engine fairings removed in the previous inspection. The TWA right-hand underwing fillet is being removed at every inspection through the remainder of the program to obtain accurate mass determinations and detect any indication of continuing moisture pickup. Difficulty has been encountered in obtaining accurate mass determinations of the parts because of the lack of accurate balances at the airline maintenance bases. The proximity of TWA's base to the Lockheed plant makes it feasible to bring in an accurate balance for the inspections. The sandwich panels are too large to weigh on this balance, but the underwing fillet can be readily weighed. This activity was initiated in 1978 on the right-hand part.

The fairings had 18,446 flight hours on Ship 1111 as of the date of inspection. These fairings had been initially installed on Ship 1026, and accumulated 2404 flight hours on that ship prior to removal and reinstallation for a total of 20,850 flight hours. The parts had accumulated 3710 hours in the year since the previous inspection.

The inspection of the Eastern fairings on Ship N313EA (Serial 1020) took place at Eastern's Atlanta Maintenance Base on October 19, 1981. This was the first inspection after reinstallation of the fairings onto Ship N313EA in October 1980. The left-hand wing-body fairing panel and the left-hand aft engine fairing panel were removed for inspection while the opposite set of panels were inspected on the aircraft. The two underwing fillet panels were misplaced by Eastern after removal from the original aircraft in 1979 and have not been found. These will be reinstalled if found, but are probably lost to the remainder of the program.

The fairings had accumulated 3013 flight hours on Ship N313EA in the year since their reinstallation. The fairings had previously accumulated 17,718 flight hours on Ship N314EA for a total of 20,731 flight hours.

Inspection of these panels was by visual examination and coin tapping for delaminations and skin-core disbonds. The panels taken off the aircraft were cleaned to remove excessive dirt and residue. The panels were then inspected for the condition of the fastener holes and the inner surface, as well as the outer surface condition which was checked on all six parts.

The inspections were conducted with the participation of Lockheed Engineering, and with the assistance of airline maintenance personnel in removal and reinstallation of the panels. Photographs were taken of all panels and areas containing defects, damage, or other conditions of special interest. Photographs were provided by Air Canada in Montreal, by the Lockheed Photography Department at TWA in Los Angeles, and by the Lockheed Field Service Office in Atlanta. Detail observations at the inspections are given in Appendices A, B and C.

DISCUSSION OF INSPECTION RESULTS

The Kevlar-49 panels continue to perform satisfactorily in service with no major damage or defects requiring corrective maintenance. Minor impact damage has occurred, with complete penetration of the skins in several instances. A few minor disbonds have also been noted, along with some incidences of fastener hole elongation. A general condition of fraying around fastener holes, resulting from the initial machining operation, has also been noted. The airlines do not regard these as serious occurrences as the fairings are lightly loaded nonstructural components which only take aerodynamic loads. Damage is therefore left unrepaired for an indefinite period or else given a cosmetic repair.

The new incidences of damage noted in the 1981 inspections were:

1. A disbonded area on the exterior surface of the Air Canada right-hand wing-body fairing.

2. A slight gouge on the inner surface of the same panel.

3. Two cracks, one of which was deeply gouged, noted on the exterior surface of the TWA right-hand wing-body fairing.

4. A small crack noted on the inner surface of the TWA left-hand wing-body fairing.

5. A small disbond on the exterior surface of the Eastern right-hand wing-body fairing.

6. A small disbond on the inner surface of the Eastern left-hand wing-body fairing.

All of these damage areas were on the wing-body fairings which are in an area more subject to ground handling damage then the other parts. Nearly all of the previously observed impact damage has also been on these parts. The incidence of damage on these prototype parts is probably greater than for standard production parts because of the increased handling during the removal and reinstallation for the annual inspections. The inner skin damage may have occurred during removal and reinstallation, but there is an access bay above these parts containing hydraulic lines, and the inner skin damage could have been caused by dropped tools. None of the previously observed impact damage areas were observed to have propagated or increased in extent. This lack of damage growth is a significant indication of acceptable damage tolerance for Kevlar-49 in these applications. In some cases the damage has remained unchanged in appearance or size for six years.

Several minor disbond areas have been observed over the past few years including the three new areas listed above. These are all limited in area, and have increased in size only slightly over observation periods up to six years. These disbonds have been noted on both the inner and outer faces of the wing-body fairings, and are not associated with visible impact damage. Possible causes are: 1) manufacturing defects resulting in localized areas

without an adequate adhesive fillet in the cell walls, 2) application of excessive heat, or 3) low level impact not showing an external crack. In one instance the disbond appears to be at the location of a Lockheed applied repair. These disbonds are probably related to adhesive fillet defects rather than delaminations in the Kevlar-49 skin. In any case the limited size and incidence of these disbonds along with the observed absence of significant disbond growth provides further evidence of Kevlar-49 damage tolerance.

While some of the minor damage observed to date has not been repaired, several repairs have been made to the Kevlar-49 parts, mostly on the exterior surfaces of the wing-body fairing sandwich panels. In previous inspections, repairs have been noted in which cracks were filled with a resin filler and in one case coated with conductive paint. Other patches consist of overlays of adhesive tape; in one case the patch has been identified as aluminum speed tape with an overcoat of paint. At least one repair of each type has been noted on the inner surface of the wing-body fairing panels. The only new repair noted in the 1981 inspections was a reworking of the aluminum speed tape repair in which the tape was removed and the crack area filled with resin and repainted.

In summary, the repair procedures used on the fairings have been cosmetic field repairs typical of the procedures used for noncritical fiberglass parts, and adaptable to either line station or maintenance base operations.

The other damage condition which has been typically observed on the Kevlar-49 panels has been fraying and elongation of fastener holes. These have been minor conditions in all instances, which have not required maintenance action or repair. Elongation of the fastener holes has occurred in a random distribution, and has been noted primarily on the underwing fillet panels. The condition is comparable to hole elongation on similar fiberglass panels which is a fairly common occurrence according to the airlines. The cause of elongation is concentrated or nonuniform bearing loads possibly resulting from installation problems or excessive hole clearances. There has been relatively little increase in the incidence or severity of this

elongation, and in the 1981 inspections no significant increase in elongation was observed over the 1980 results.

The fastener hole fraying appears to be a general occurrence on Kevlar-49 holes and edges where less than optimum machining procedures have been used. The fraying noted on these parts appears to be primarily the result of the initial machining operation, as this condition has remained essentially unchanged with increasing service life. These parts were fabricated in 1972 when development of Kevlar-49 machining techniques was in a very early stage, and the degree of fraying may therefore be more severe than for currently fabricated parts. In previous inspections, it has been observed that some of the aft engine fairings and underwing fillets have noticeably less fraying than others. This indicates that variations in machining techniques and operator skills at the time of installation was a significant factor in the degree of fraying. It has also been noted that the elongated holes in the underwing fillets generally have more fraying than the other holes, indicating that in-service loads can aggravate the initial fraying. There is no evidence that the frayed condition in any way affects part performance.

The fastener holes on the Eastern fairings were observed for the first time since their reinstallation which involved relocation of all fastener holes. The original fastener holes were filled, and new holes were drilled. These new fastener holes were observed to have a great amount of fuzz which creates the frayed appearance noted in other inspections. This condition was much more pronounced than in any of the other Kevlar-49 parts (including the original fastener holes on the Eastern panels). As mentioned in the preceding paragraph, the frayed appearance is the result of the initial drilling operation. This condition therefore indicates that non-optimum procedures and tools were used in the drilling of the relocated holes. Some holes were drilled partially through the chopped glass filled epoxy filler. These areas had no fuzz, but did have a greater incidence of elongation than has been noted for holes drilled through the Kevlar-49. No elongation was observed in any of the relocated holes drilled through the Kevlar-49. The frayed condition does not appear therefore to significantly affect performance of these

parts. The fuzz was observed to be almost entirely on the inner surface, which may account for the report made in last year's report of a relative absence of fuzz after visible examination.

The Kevlar-49 parts have not been affected to any discernible degree by exposure to Skydrol or other aircraft fluids, but the presence of Skydrol has been observed on all three components. The Skydrol appears to have attacked a vapor barrier coating on some of the aft engine fairings. Paint adhesion to the Kevlar-49 surfaces appears to be comparable to fiberglass parts, as would be expected.

The Kevlar-49 parts have been weighed on the occasions when they have been removed. The effects of paint loss, repainting, resealing, and repair have masked any mass change due to moisture pickup; and determination of mass changes has been hampered by the lack of suitable balances at the airline maintenance bases. A balance has been brought from Lockheed to the TWA base in Los Angeles for weighing of the small underwing fillet panel in the last four inspections. Accurate mass determinations have been obtained on the right-hand fillet (Appendix B), and the mass of this part will be monitored throughout the remainder of the program. Results to date show no significant weight change over two years; and the part apparently had reached moisture equilibrium by the time the weighings started in 1978, as would be expected.

GROUND-BASED ENVIRONMENTAL EXPOSURE[1]

Along with the flight service evaluation, a ground exposure program is being conducted to determine the effects of outdoor environment on several composite material systems including Kevlar 49/F-155 and Kevlar 49/F-161. Replicate short beam shear, compression and flexure specimens have been mounted on racks (see Figure 4) and placed at six locations worldwide (see Figure 5). The specimens are removed at periods of 1, 3, 5, 7, and 10 years. All specimens, once removed from the rack, are weighed and tested. Flexure

[1]Work performed by Jane A. Hagaman of the NASA Langley Research Center.

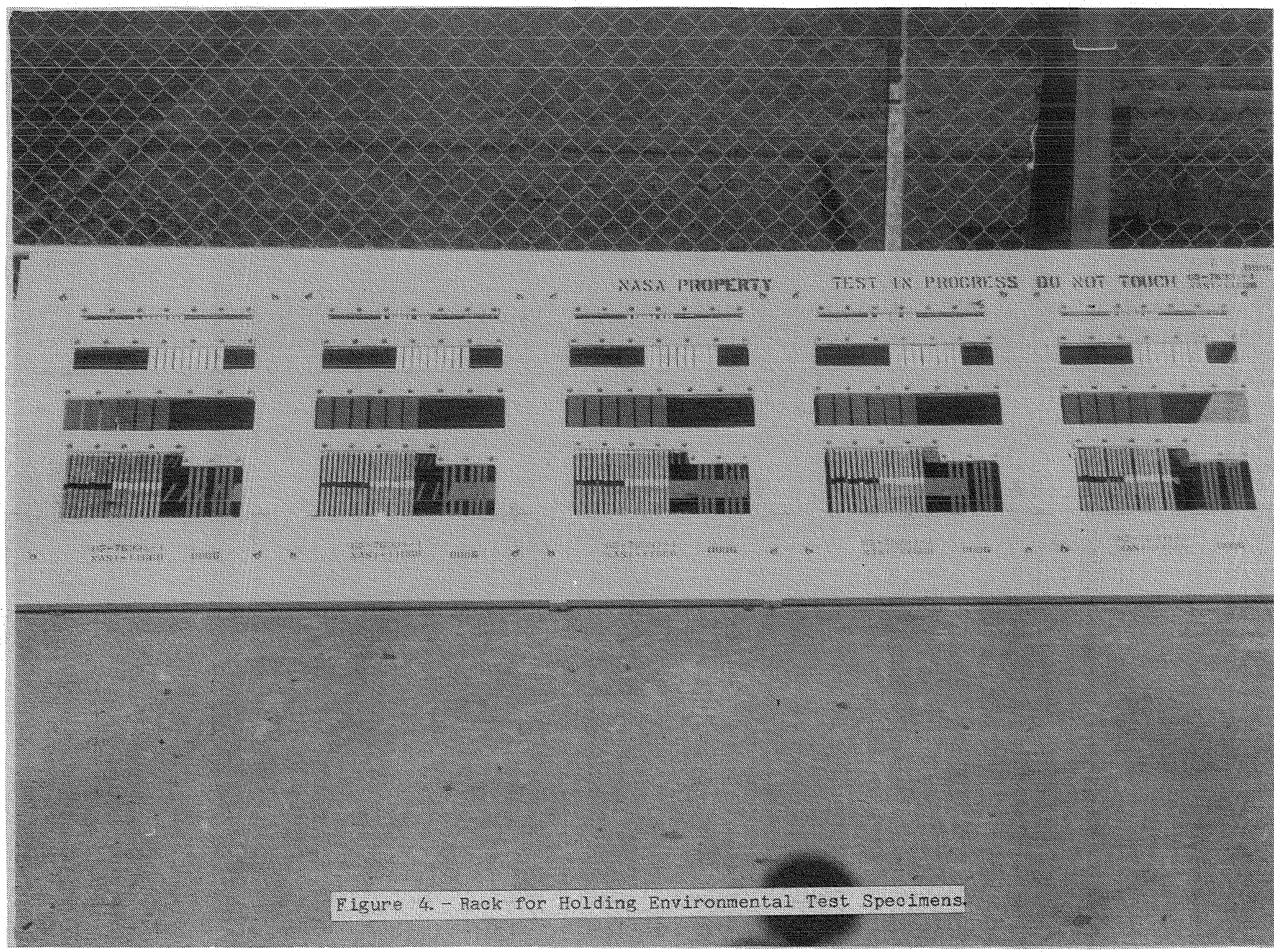

Figure 4. - Rack for Holding Environmental Test Specimens.

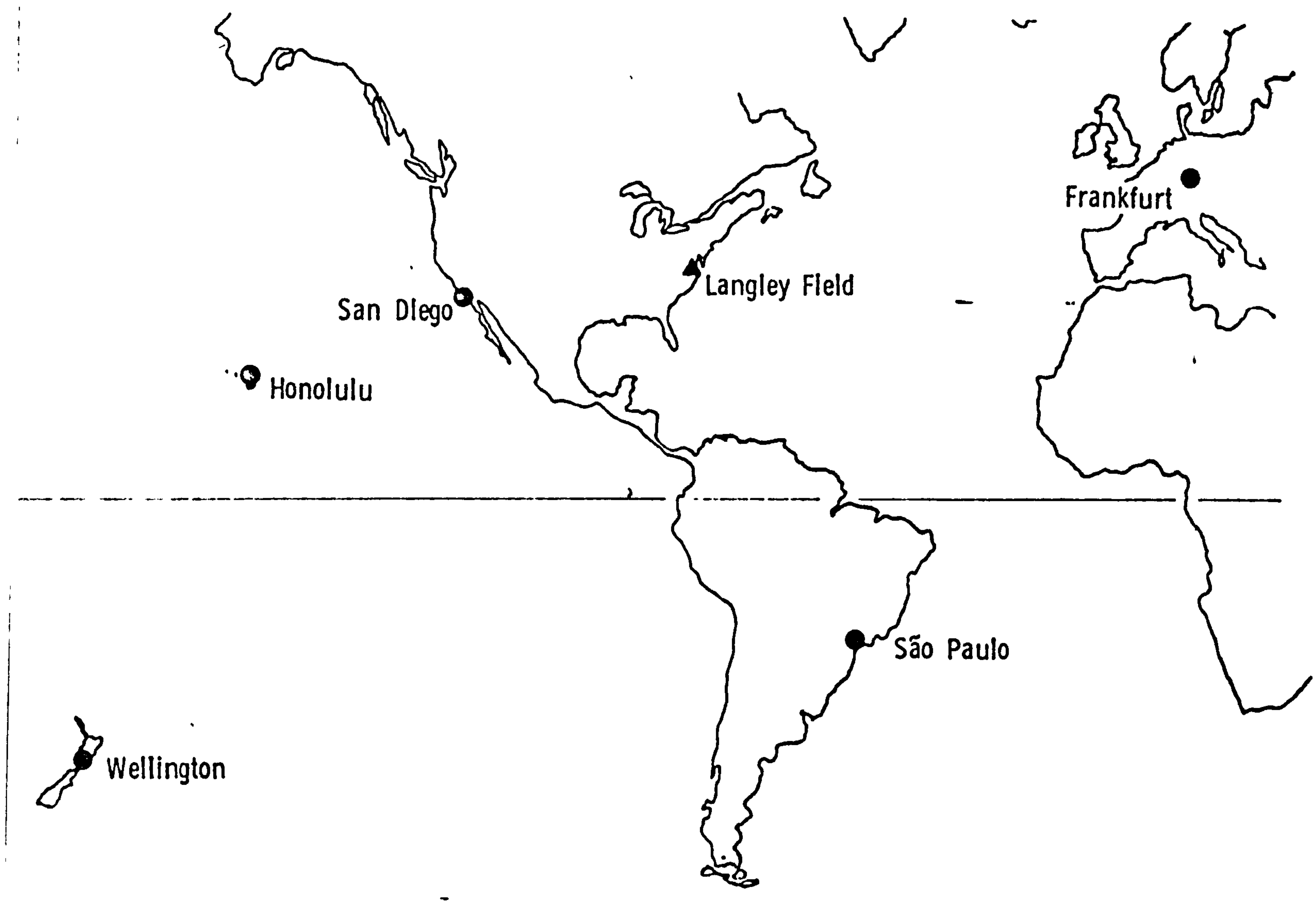

Figure 5.- Worldwide Distribution of Environmental Exposure Racks.

specimens are weighed again after testing and then dried to determine moisture pickup. Specimens are evaluated for strength retention, moisture pickup and ultraviolet weight loss. Data from 1 and 3 years exposure are reported in reference 5. This report includes all available data for specimens exposed for 5 and 7 years.

Table 1 shows the moisture pickup and ultraviolet weight loss for flexure specimens exposed for five years. Over the 3 and 5 year exposure periods, the moisture pickup has remained fairly constant, however specimens at all locations continue to lose weight due to the effects of ultraviolet radiation. Although exposure to ultraviolet radiation can degrade the composite matrix, this degradation can be prevented by coating the specimen with standard polyurethane aircraft paint.

The moisture pickup over a 5 year period is shown in Figure 6. On a world-wide basis, both systems appear to be stabilizing slightly above 2 percent moisture pickup. Since 7 year specimens have not fully dried, these data are not yet available.

Tables 2, 3 and 4 show the shear, compression and flexure strengths, respectively, for all the 5 and 7 year specimens. The average baseline strength value is also shown for each material system. Figures 7 through 12 show 5 and 7 year strength ratios for both material systems. The strength ratio is a comparison of the average specimen strength with the average baseline strength for the material system. There is some degradation in shear strength for both systems over the 7-year period. However, both Aloha and Lufthansa specimens show shear strength ratio values about 13 percent above the baseline value for Kevlar 49/F-161. The greatest strength reduction (28 percent) is for the Kevlar/F-155 specimens exposed in Brazil for 7 years. Compression strength ratio values have also degraded somewhat after 7 years exposure with a maximum 18-20 percent strength reduction in 7-year VASP specimens. Flexure strength ratio values are relatively stable throughout the 7-year period with values for the Kevlar 49/F-155 system generally lower than those for the Kevlar 49/F-161 system. The maximum flexure strength reduction (16 percent) is for Kevlar 49/F-155 specimens exposed in California for 7 years.

The final rack of 10-year specimens will be evaluated in 1983.

TABLE 1. MOISTURE PICKUP AND ULTRAVIOLET LOSSES FOR KEVLAR/EPOXY FLEXURE COUPONS AFTER 5 YEARS WORLDWIDE EXPOSURES

Exposure site	Moisture pickup, percent		UV weight loss, mg/cm^2	
	F-155	F-161	F-155	F-161
LaRC	2.12	2.39	9.11	6.34
California	2.10	2.17	9.59	5.36
New Zealand	2.30	2.47	9.59	5.91
Hawaii	2.19	2.27	12.73	8.50
Germany	1.82	2.10	5.57	2.54
Brazil	2.38	2.61	9.06	5.33

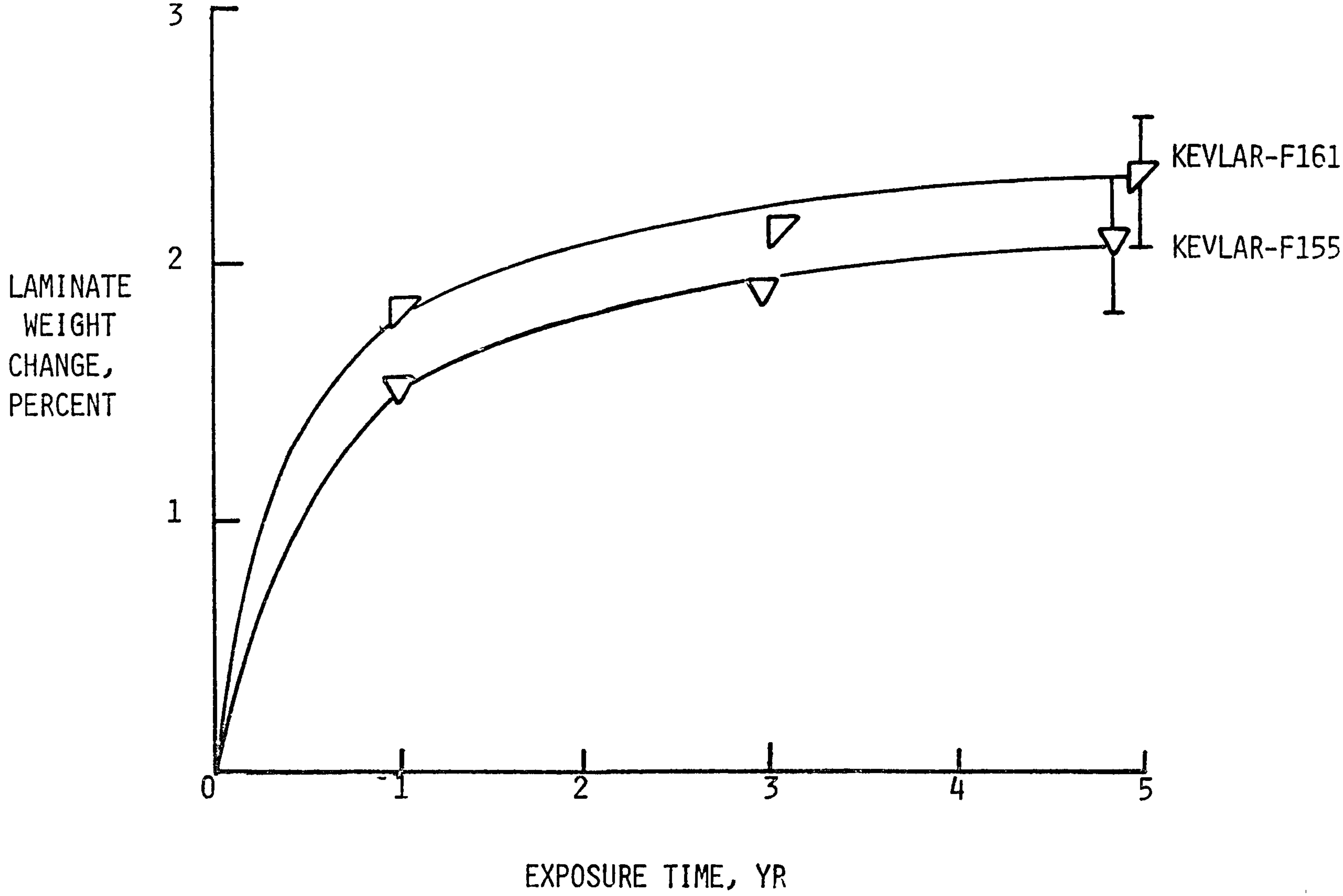

Figure 6. - Moisture Pickup for Flexure Specimens After Worldwide Exposure.

TABLE 2. RESULTS OF GROUND-BASED ENVIRONMENTAL EXPOSURE ON KEVLAR/EPOXY MECHANICAL PROPERTY TEST SPECIMENS - SHORT BEAM INTERLAMINAR SHEAR TESTS

Exposure time, yr	Exposure location	Kevlar/epoxy system	Number of specimens	Average failure stress	
				MPa	ksi
0 (Baseline)	LaRC	F-155	7	47.9	6.94
5	LaRC		3	39.6	5.74
5	California		3	41.0	5.95
5	New Zealand		3	37.4	5.43
5	Hawaii		3	45.9	6.66
5	Germany		3	47.7	6.92
5	Brazil		3	39.6	5.74
7	LaRC	F-155	3	41.0	5.94
7	California		3	41.5	6.02
7	New Zealand		3	39.4	5.72
7	Hawaii		3	40.9	5.93
7	Germany		3	41.5	6.02
7	Brazil		3	34.4	4.99
0 (Baseline)	LaRC	F-161	5	32.4	4.70
5	LaRC		3	31.0	4.50
5	California		3	26.4	3.83
5	New Zealand		3	29.8	4.32
5	Hawaii		3	36.8	5.33
5	Germany		3	36.7	5.32
5	Brazil		3	33.0	4.78
7	LaRC	F-161	3	30.5	4.42
7	California		3	29.0	4.20
7	New Zealand		3	30.7	4.45
7	Hawaii		3	28.0	4.06
7	Germany		3	31.0	4.50
7	Brazil		3	29.0	4.21

TABLE 3. RESULTS OF GROUND-BASED ENVIRONMENTAL EXPOSURE ON KEVLAR/EPOXY MECHANICAL PROPERTY TEST SPECIMENS - COMPRESSION TESTS

Exposure time, yr	Exposure location	Kevlar/epoxy system	Number of specimens	Average failure stress	
				MPa	ksi
0 (Baseline)	LaRC	F-155	5	137.3	19.92
5	LaRC		3	117.2	17.00
5	California		3	121.6	17.63
5	New Zealand		3	121.5	17.62
5	Hawaii		3	115.2	16.71
5	Germany		3	128.3	18.61
5	Brazil		2	118.7	17.21
7	LaRC	F-155	3	123.8	17.96
7	California		3	136.6	19.82
7	New Zealand		3	130.6	18.94
7	Hawaii		3	127.6	18.51
7	Germany		3	136.9	19.86
7	Brazil		3	113.0	16.39
0 (Baseline)	LaRC	F-161	5	128.0	18.56
5	LaRC		3	107.1	15.54
5	California		3	113.4	16.45
5	New Zealand		3	107.7	15.62
5	Hawaii		3	105.6	15.31
5	Germany		3	113.5	16.46
5	Brazil		3	98.8	14.33
7	LaRC	F-161	3	118.2	17.14
7	California		3	126.6	18.36
7	New Zealand		3	119.2	17.29
7	Hawaii		3	121.0	17.55
7	Germany		3	121.1	17.56
7	Brazil		3	102.0	14.79

TABLE 4. RESULTS OF GROUND-BASED ENVIRONMENTAL EXPOSURE ON KEVLAR/EPOXY MECHANICAL PROPERTY TEST SPECIMENS - FLEXURE TESTS

Exposure time, yr	Exposure location	Kevlar/epoxy system	Number of specimens	Average failure stress		Average flexu modulus	
				MPa	ksi	GPa	psi (× 10
0 (Baseline)	LaRC	F-155	6	396.2	57.46	25.0	3.63
5	LaRC	↓	3	346.7	50.29	20.8	3.01
5	California		3	344.3	49.94	21.4	3.10
5	New Zealand		3	326.5	47.36	19.7	2.86
5	Hawaii		3	323.1	46.86	20.4	2.96
5	Germany		3	356.4	51.69	20.6	2.98
5	Brazil		3	342.5	49.67	22.8	3.31
7	LaRC	F-155	3	359.0	52.07	19.4	2.82
7	California	↓	3	337.9	49.01	21.3	3.09
7	New Zealand		3	342.7	49.71	19.2	2.79
7	Hawaii		3	321.7	46.66	18.1	2.62
7	Germany		3	399.1	57.89	20.5	2.97
7	Brazil		3	324.5	47.06	20.2	2.93
0 (Baseline)	LaRC	F-161	5	375.4	54.45	24.4	3.54
5	LaRC	↓	3	353.4	51.26	22.0	3.19
5	California		3	371.9	53.94	22.9	3.32
5	New Zealand		3	346.1	50.20	21.8	3.16
5	Hawaii		3	353.2	51.22	22.0	3.19
5	Germany		3	367.5	53.30	21.4	3.11
5	Brazil		3	363.3	52.69	24.8	3.59
7	LaRC	F-161	3	352.5	51.13	22.8	3.30
7	California	↓	3	343.4	49.81	23.2	3.37
7	New Zealand		3	357.3	51.82	21.2	3.08
7	Hawaii		3	346.2	50.21	20.3	2.94
7	Germany		3	367.0	53.23	21.7	3.15
7	Brazil		3	341.6	49.55	23.2	3.37

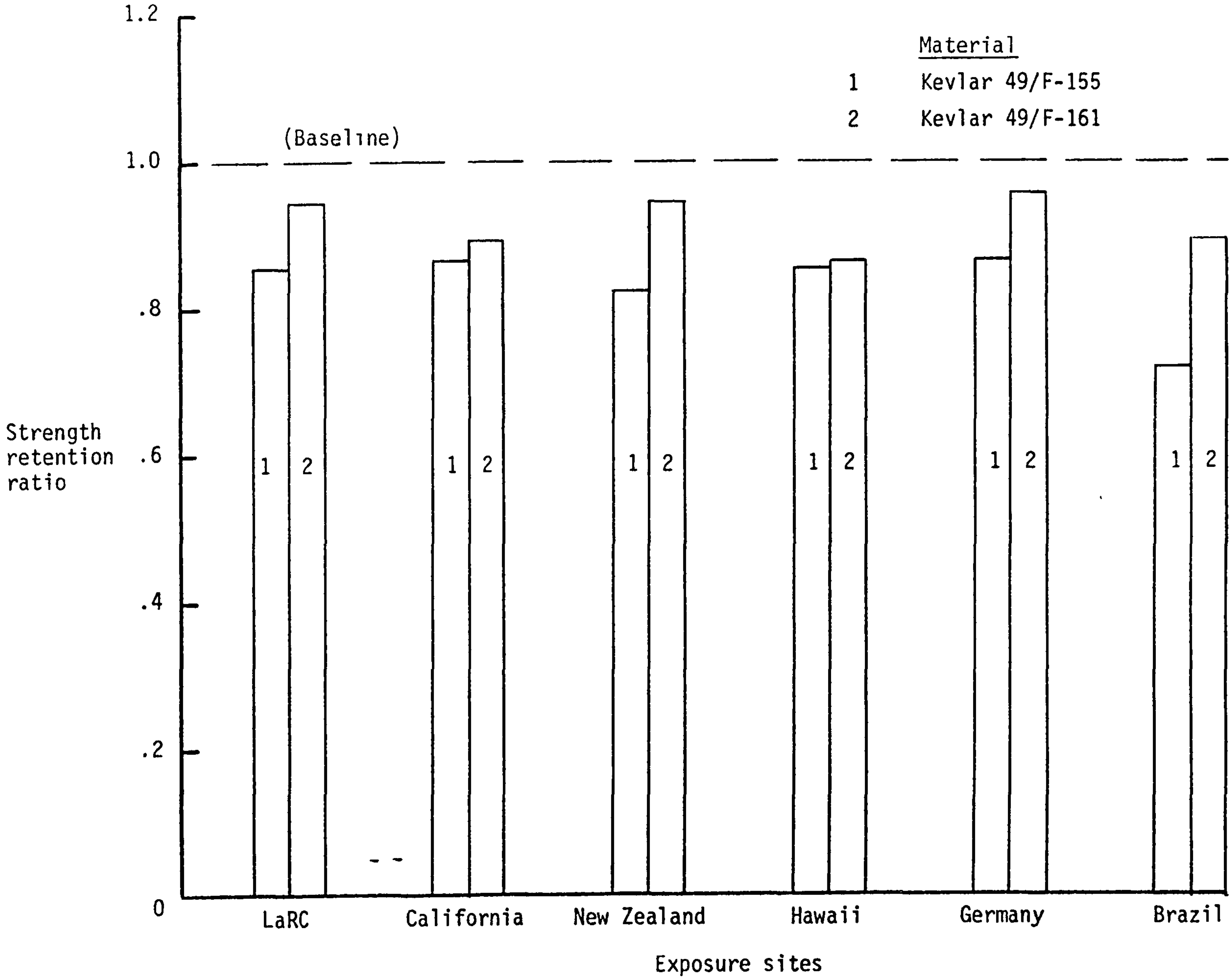

Figure 7. - RT Shear Strength Retention of Kevlar/Epoxy After 5 Years Outdoor Ground-Based Exposure.

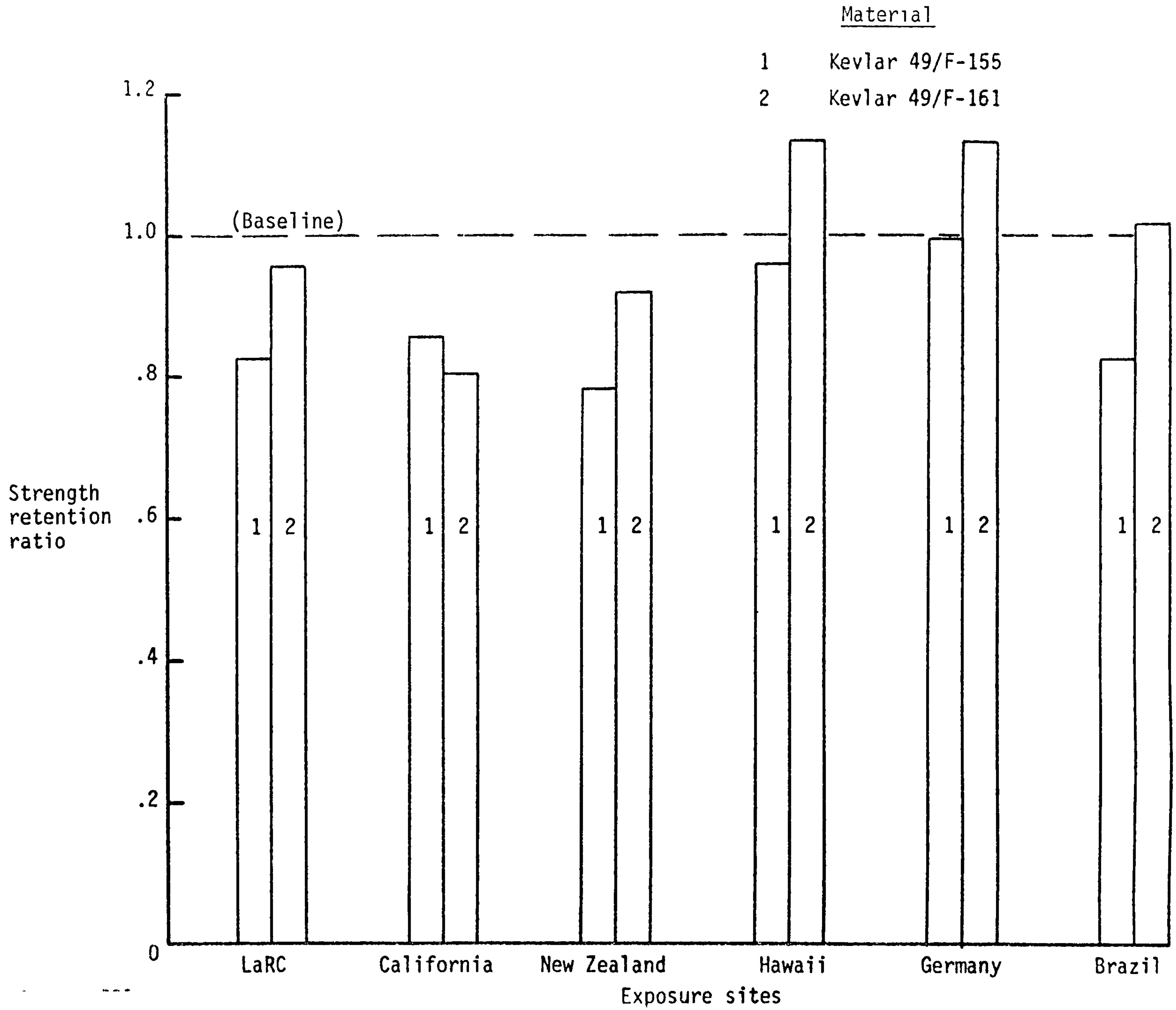

Figure 8. - RT Shear Strength Retention of Kevlar/Epoxy After 7 Years Outdoor Ground-Based Exposure.

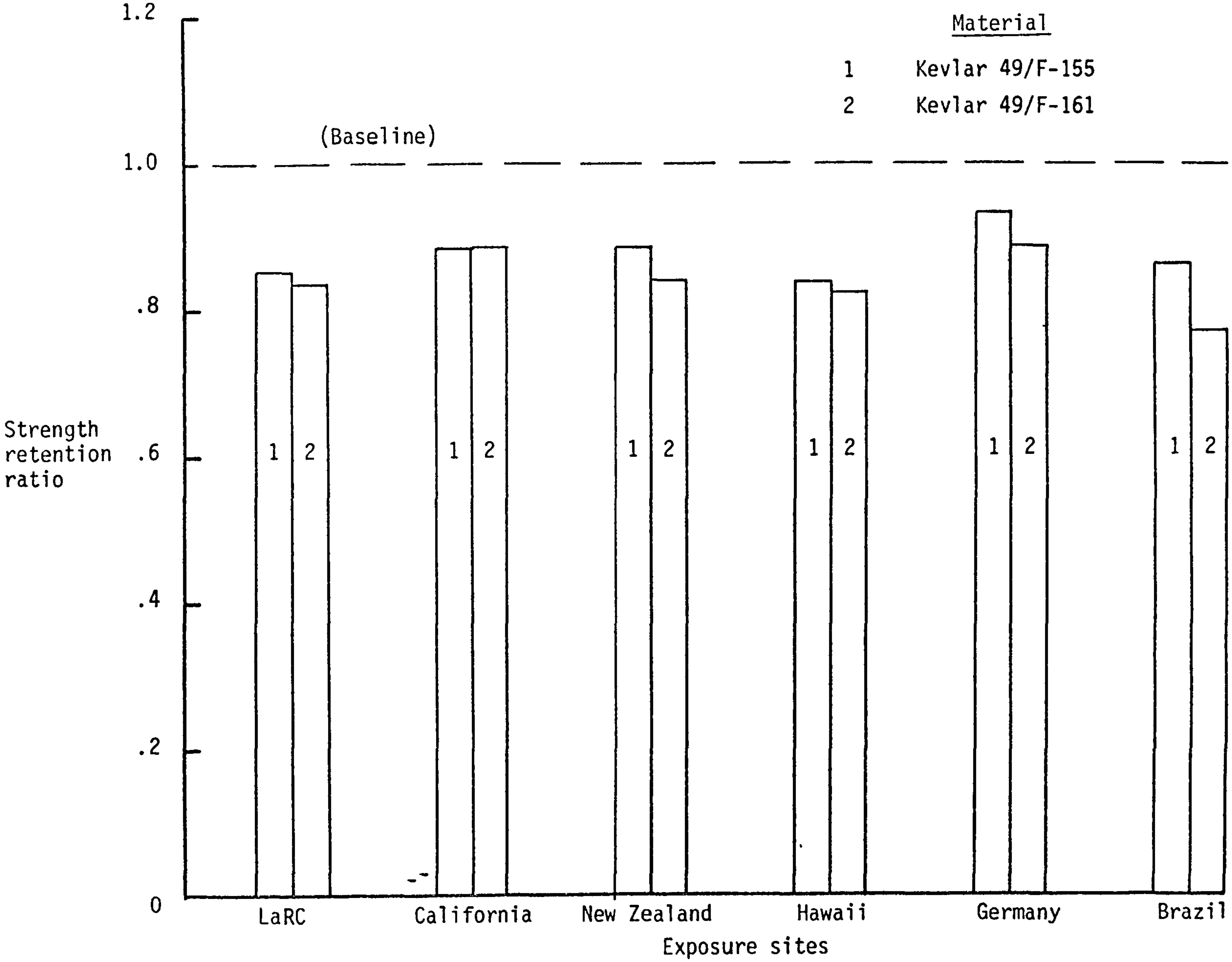

Figure 9. - RT Compressive Strength Retention of Kevlar/Epoxy After 5 Years Outdoor Ground-Based Exposure.

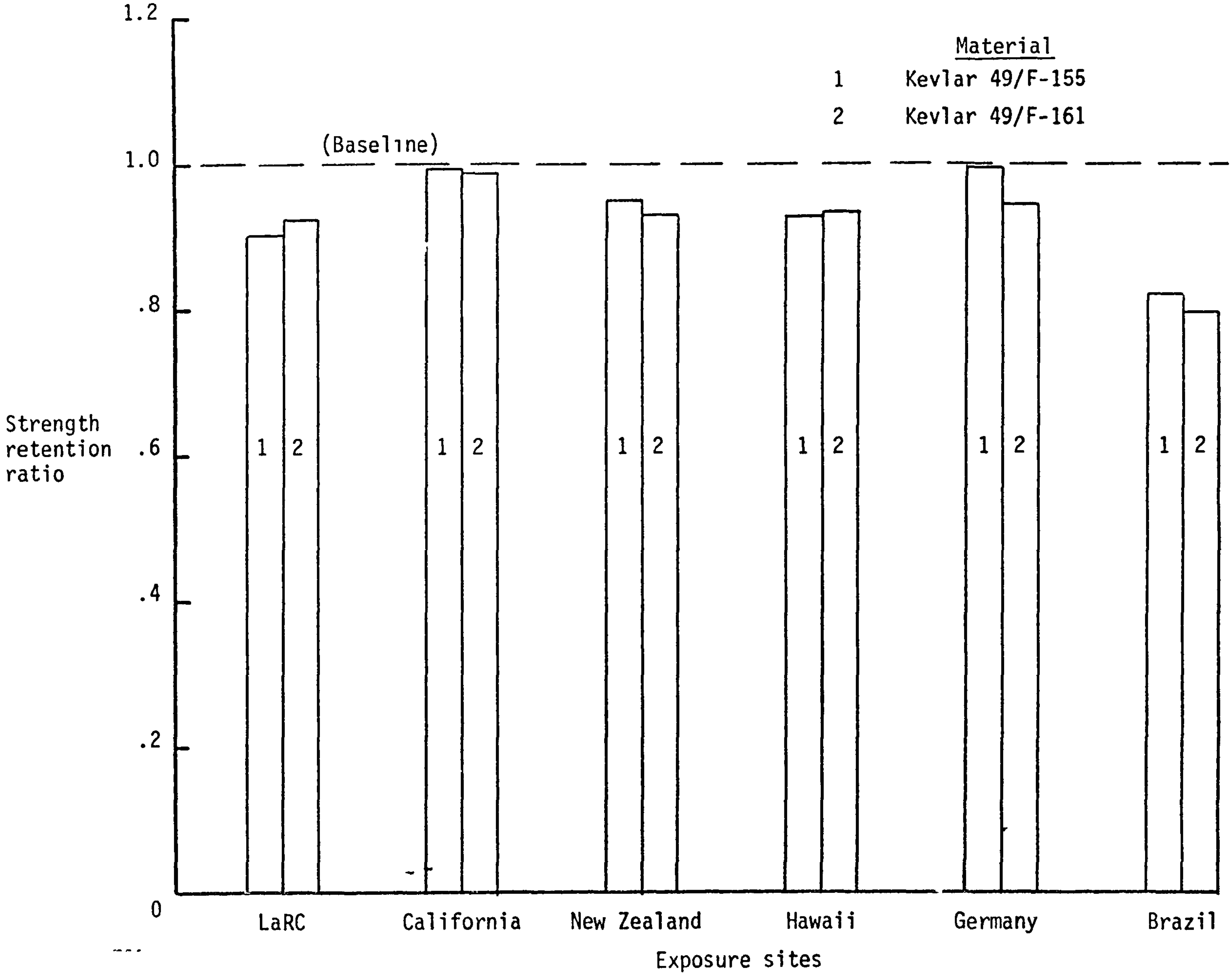

Figure 10. - RT Compressive Strength Retention of Kevlar/Epoxy After 7 Years Outdoor Ground-Based Exposure.

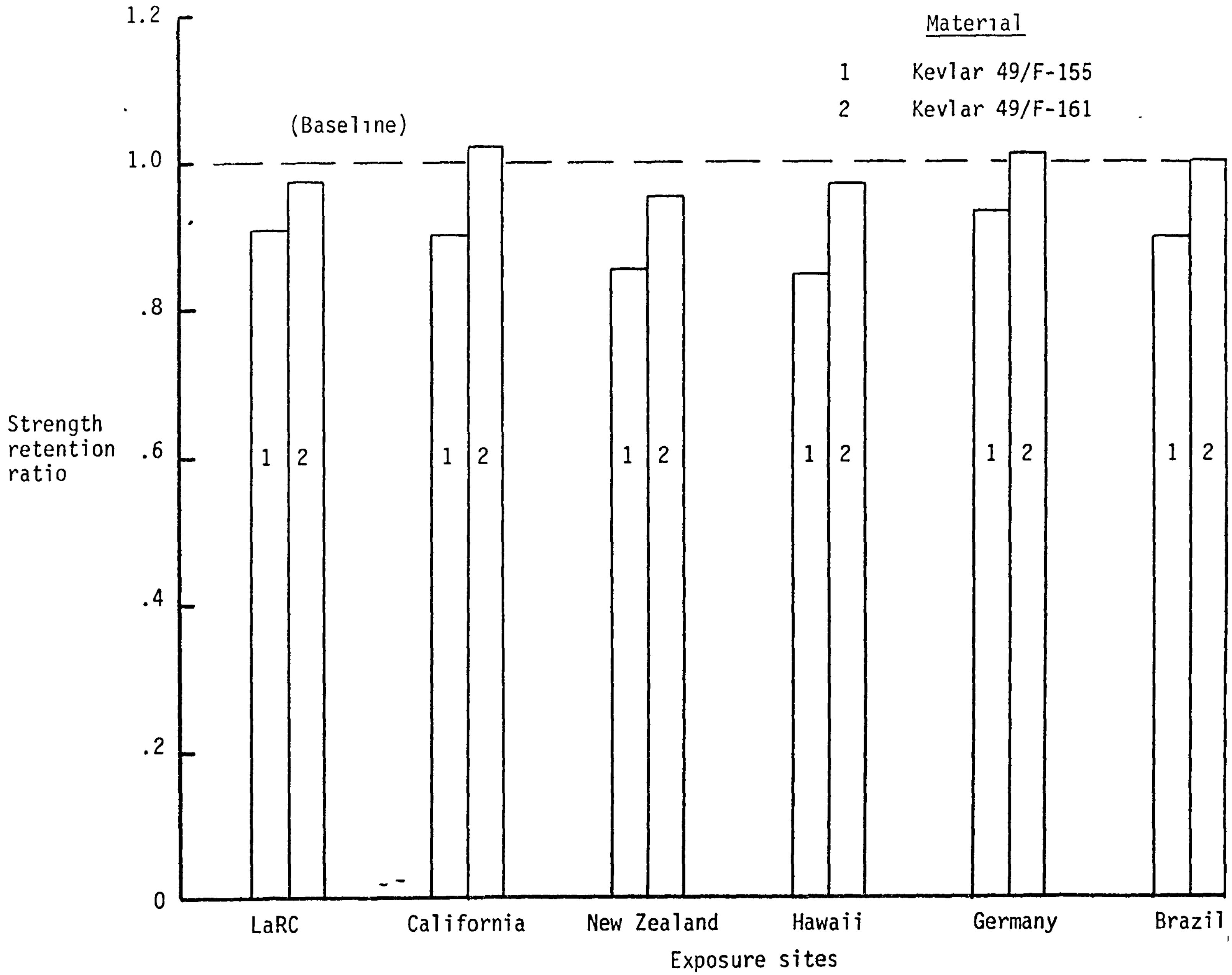

Figure 11. - RT Flexure Strength Retention of Kevlar/Epoxy After 5 Years Outdoor Ground-Based Exposure.

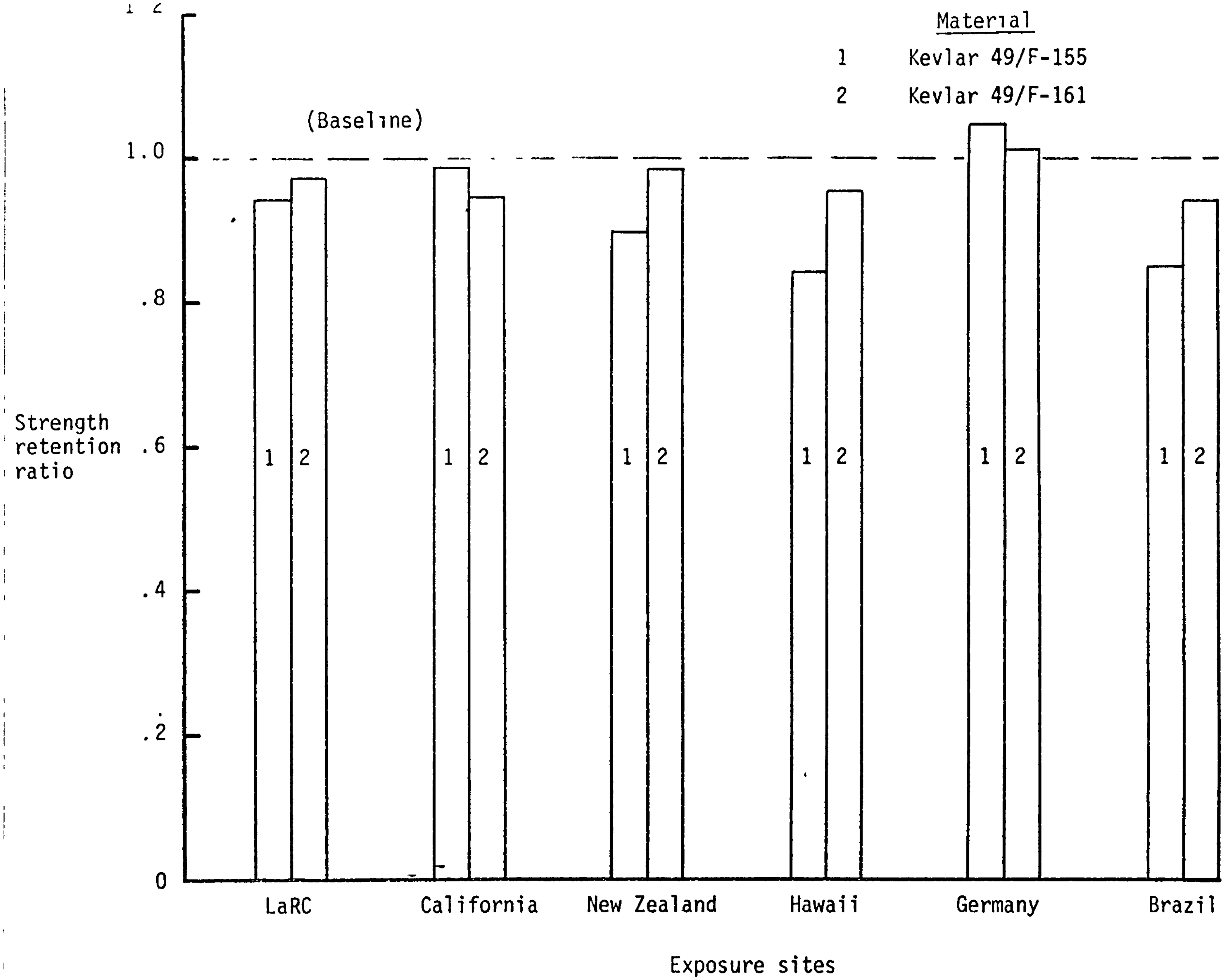

Figure 12. - RT Flexure Strength Retention of Kevlar/Epoxy After 7 Years Outdoor Ground-Based Exposure.

SUMMARY OF RESULTS AND CONCLUSIONS

The Kevlar-49 fairing panels continue to perform satisfactorily and are free of major damage or defects after 8 years of service and a total of 62,000 flight hours on the three aircraft.

The following types of minor damage have been noted: cracks resulting from impact observed principally on the wing-body fairings; small disbond areas also noted primarily on the wing-body fairings; and fraying and elongation of fastener holes. The cracks are primarily the result of ground handling damage while the disbonds are probably related to defects in the adhesive fillet at the skin-core bondline. The fastener hole fraying appears to be primarily the result of the initial drilling and installation procedures, aggravated in a few instances by in-service loads; while the elongation is probably related to nonuniform bearing loads caused by installation problems or excessive hole clearances. The absence of crack growth, disbond growth or significantly increased hole elongation, and the random limited occurrence of the hole elongation indicates that Kevlar-49 is resistant to damage propagation under the relatively light loading conditions typical of fairings. The fastener hole fuzziness and frayed appearance is the only damage condition observed on the Kevlar-49 parts which is not also typical of similar fiberglass parts. The fuzzing has not increased in severity with increasing service life, and does not have any apparent effect on part performance.

The Kevlar-49 skins have been free of delaminations, and no defects have been observed which can be attributed to moisture or other environmental factors. These findings indicate that two properties of Kevlar-49 which have been of concern - the poor resin-fiber interface bond and the moisture pickup of the Kevlar-49 fibers - have not seriously affected part performance.

The repairs which have been performed on these parts are typical cosmetic repairs, such as resin filling of surface cracks and applications of tape over damage areas. This type of repair is typically performed on fiberglass secondary structures, and these observations indicate that Kevlar-49 parts can be repaired in the same manner as fiberglass parts.

The ground based environmental exposure tests performed by NASA-Langley indicates that moisture pickup is stabilizing slightly above 2 percent over a 5-year exposure period. Ultraviolet exposure effects over this period result in a net weight loss for these unpainted coupons, but these effects would not occur in a painted aircraft component. Flexural strength shows little reduction after 5 and 7 years exposure. Shear and compression strengths, which are more matrix dependent than flexure, have reductions after 5 and 7 years' exposure in the 15 to 20 percent range, although there is data scatter. Greater reductions are generally seen with the 121°C (250°F) curing F-155 resin.

In summary, Kevlar-49/epoxy appears to provide service life and structural performance for lightly loaded secondary structures equivalent to that of fiberglass/epoxy.

APPENDIX A

DETAIL OBSERVATIONS OF KEVLAR-49 FAIRING PANELS - AIR CANADA SHIP CF-TNB-502 (SERIAL 1021)

JULY 1981

Three of the six fairing panels were removed for inspection: the right-hand wing-body fairing and underwing fillet panels, and the left-hand aft engine fairing. The other panels were inspected in place on the aircraft.

RIGHT-HAND WING-BODY FAIRING

1. Two exterior surface cracks observed in earlier inspections had not propagated or changed in appearance. These were a 0.3 cm (1/8 in.) crack in the center area first observed in 1976, and a 0.6 cm (1/4 in.) crack in the forward center area first observed in 1975. (Figure A-1)

2. A disbond area was noted in the upper aft portion of the exterior surface. There was no break in the skin, and the paint and flame spray were intact except for two very small areas of paint loss. The disbond area was 11.4 by 1.6 cm (4-1/2 by 5/8 in.).

3. Three delaminated areas on the inner skin, first observed in 1977, were noted as follows:

   - A disbond in the upper center area of the part had increased slightly in width since last observed in 1979, and measured approximately 12.7 by 1.3 cm (5 by 1/2 in.).

   - A disbond close to the first area had increased in area slightly since 1979 and measured approximately 3.8 by 3.5 cm (1-1/2 by 1-3/8 in.).

   - A disbond in the lower forward area of the part had increased slightly in width since 1979, and measured approximately 10.2 cm by 1.3-1.9 cm (4 in. by 1/2-3/4 in.).

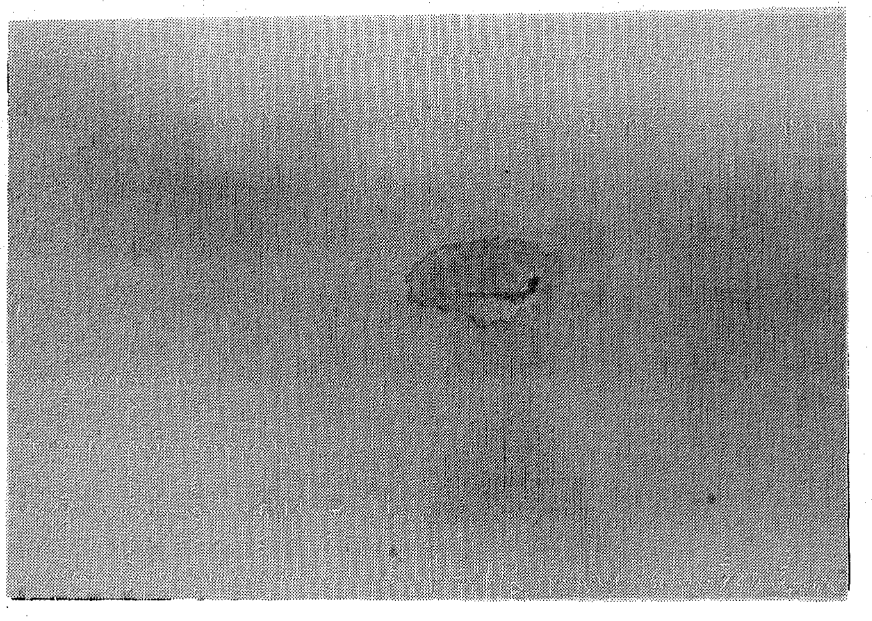

Figure A-1. - Air Canada Right-Hand Wing-Body Fairing - 0.6 cm Crack on Exterior.

4. A gouged area with loose fibers, 1.9 cm (3/4 in.) in length in the lower forward area of the inner surface (Figure A-2), had not changed or increased in size since first observed in 1979.

5. Another gouged area, smaller and shallower than the first, was observed in the upper forward area of the inner skin. This was 0.3 cm (1/8 in.) in length, and had not been observed perviously.

6. An area on the inner skin near the two upper disbonds was first observed in 1977 to have an overlay, presumably a repair patch, which had been sanded. This had an area of 26.7 by 3.8 cm (10-1/2 by 1-1/2 in.) and was unchanged in appearance of size since the 1979 inspection.

7. Slight fraying was observed on all fastener holes on the top, forward and aft edges. There was a greater degree of fraying along with a distinct fastener markoff on the lower edge. (Figure A-3). This condition has remained unchanged from the previous inspections.

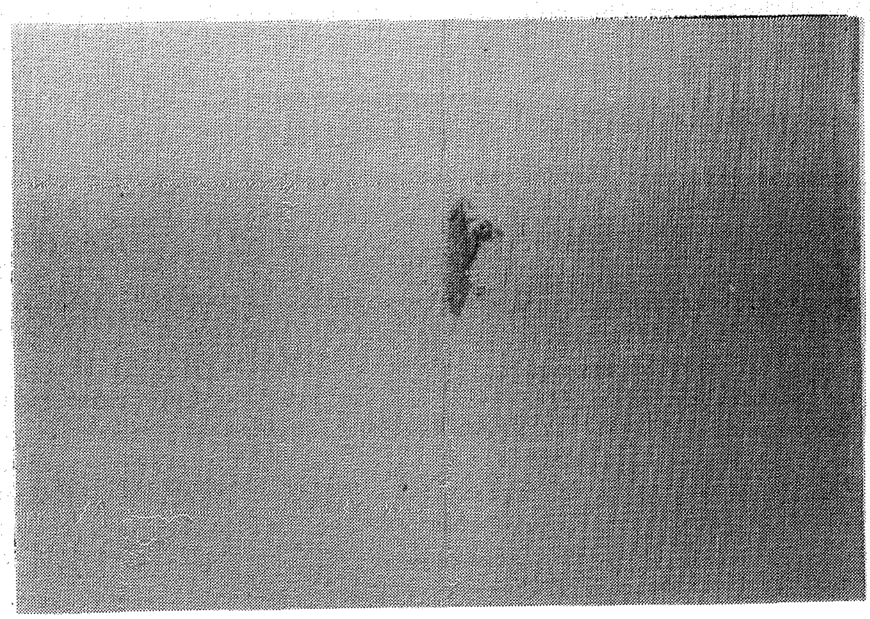

Figure A-2. - Air Canada Right-Hand Wing-Body Fairing - Gouged Area on Inner Surface.

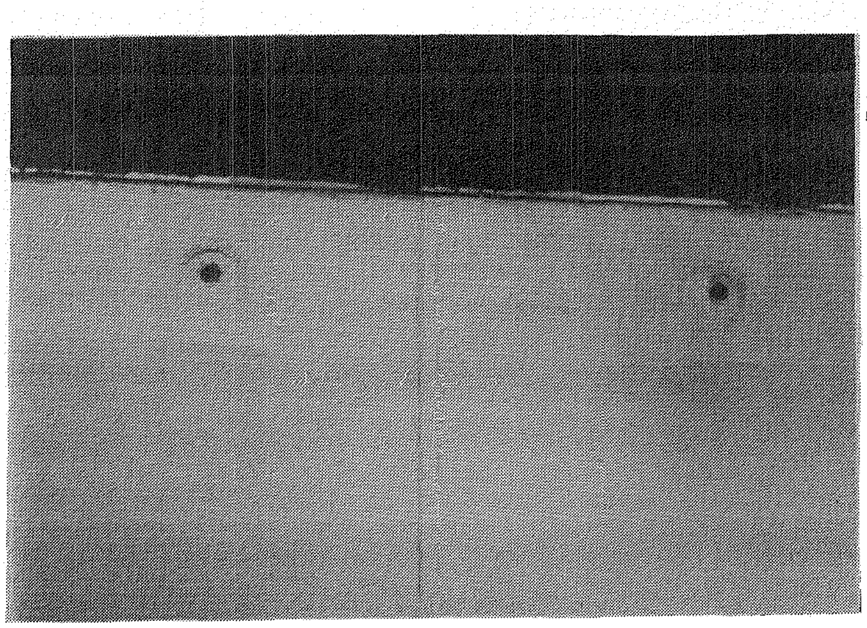

Figure A-3. - Air Canada Right-Hand Wing-Body Fairing - Frayed Holes on Lower Edge.

8. Several elongated holes were noted, and the incidence of this condition has increased slightly since the 1979 inspection. These included holes on the top, aft and lower edges. The degree of elongation was slight, not exceeding 0.55 cm (7/32 in.) from the original 0.5 cm (3/16 in.) dimension.

RIGHT-HAND UNDERWING FILLET

1. No exterior defects or damage was noted. Extensive paint loss was observed with about 60 percent of the Kevlar-49 exposed in the upper section. This indicates possible exposure to Skydrol.

2. All of the fastener holes showed some fraying and fuzz (Figure A-4). Six holes (out of 19) showed a significantly greater degree of fraying than the others. About half the holes showed measurable elongation to a 0.55 cm (7/32 in.) diameter from the original 0.5 cm (3/16 in.) diameter (Figure A-4). One hole was elongated to 0.6 cm (1/4 in.). There was no correlation between the frayed and elongated holes.

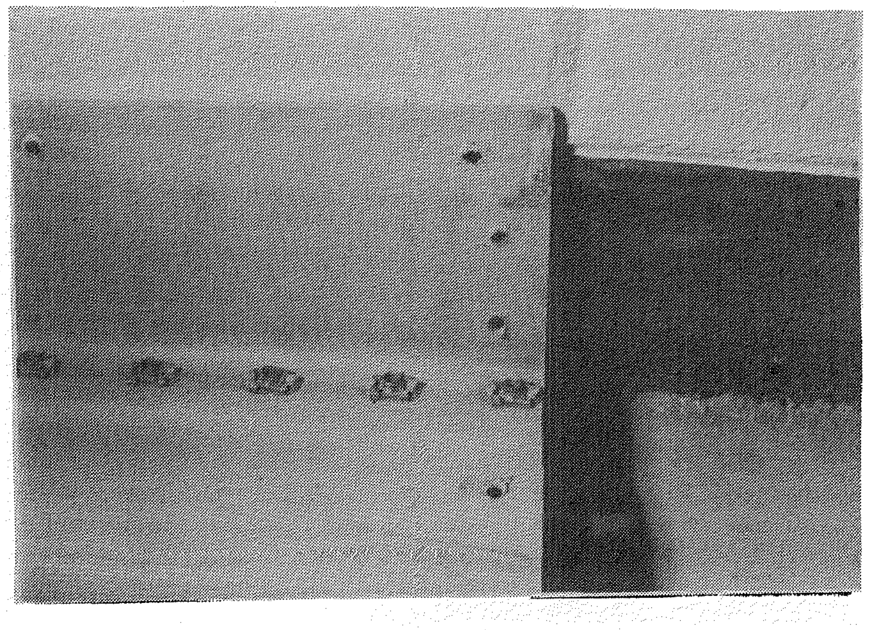

Figure A-4. - Air Canada Right-Hand Underwing Fillet - Frayed and Elongated Holes.

LEFT-HAND AFT ENGINE FAIRING

1. No exterior surface defects, damage, or paint loss was observed.

2. All of the fastener holes were heavily frayed (Figure A-5). A small number of holes were slightly elongated; three holes were elongated to 0.55 cm (7/32 in.) and one hole to 0.6 cm (1/4 in.) from the original 0.5 cm (3/16 in.) dimension.

LEFT-HAND WING-BODY FAIRING

1. A deep gouge in the upper center area of the panel exterior, 0.4 by 0.6 cm (5/32 by 1/4 in.), had not changed in size or appearance since the previous inspection (Figure A-6). This was first observed in 1978.

2. Several gouges, noted on the lower forward edges in previous inspections when the part was removed, were not detectable with the part on the aircraft.

3. A repair of a 3.2 cm (1-1/4 in.) crack made between the 1977 and 1978 inspections had been repainted, but was otherwise unchanged in appearance.

LEFT-HAND UNDERWING FILLET

1. No surface damage or defects were noted, although there was extensive paint loss, particularly in the upper section where the Kevlar-49 was almost completely exposed. Paint blistering was also noted in the lower section. The location of this part protects it from ultraviolet exposure. A slight bulge was noted along the upper aft edge between two of the fasteners. This condition, noted previously on the fillet panels, indicates installation problems or a slight misfit which could contribute to the fastener hole elongation noted on these parts.

RIGHT-HAND AFT ENGINE FAIRING

1. No damage or defects were noted on either surface. The part had been repainted since the previous inspection, and the paint blistering (possibly from Skydrol) noted in previous inspections was not evident.

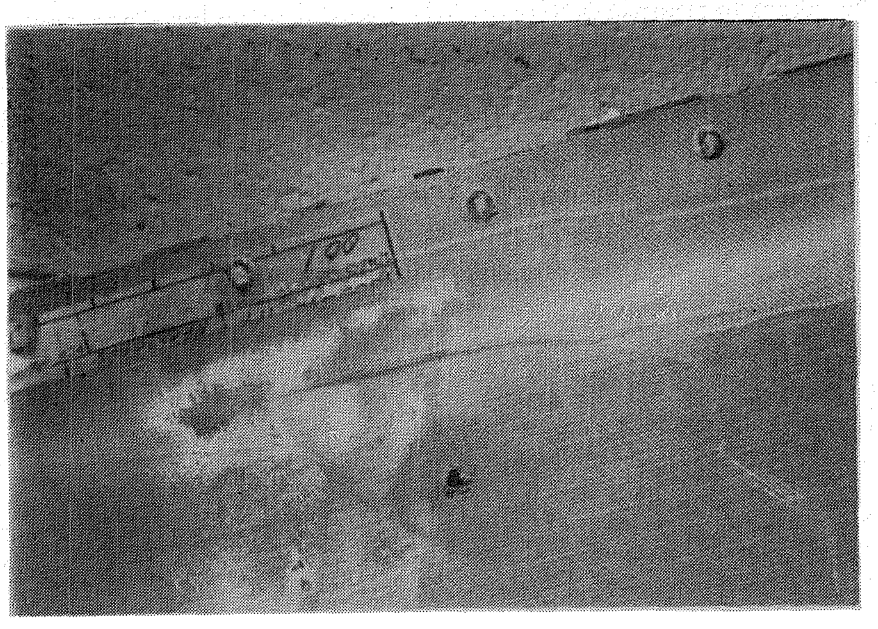

Figure A-5. - Air Canada Left-Hand Aft Engine Fairing -
Frayed Edge and Intercostal Holes.

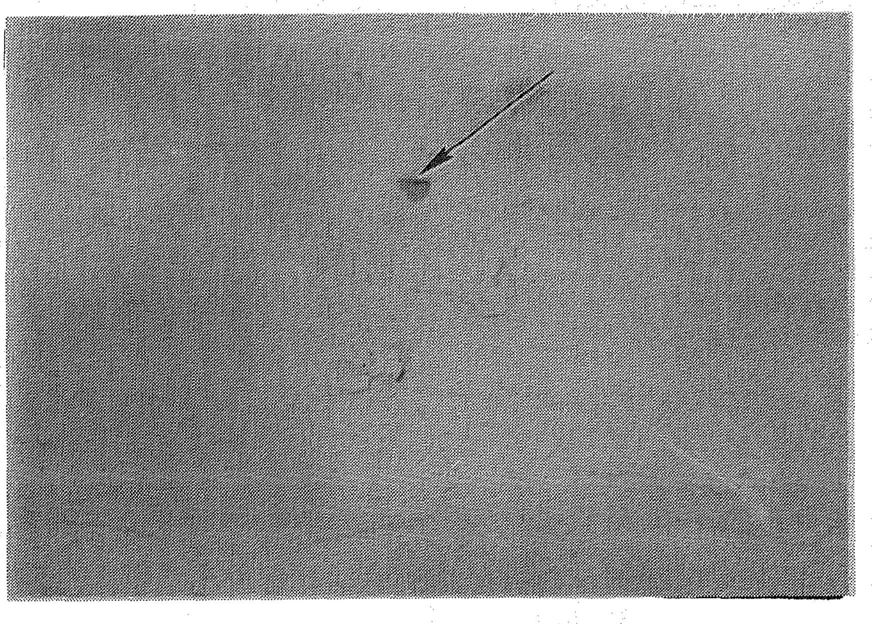

Figure A-6. - Air Canada Left-Hand Wing-Body Fairing -
Deep Gouge on Panel Exterior.

APPENDIX B

DETAIL OBSERVATIONS OF

KEVLAR-49 FAIRING PANELS -

TWA SHIP N31030 (SERIAL 1111)

SEPTEMBER 1981

Three of the six fairings were removed for inspection: the right-hand wing-body fairing and underwing fillet panels and the left-hand aft engine fairing. The other panels were inspected in place on the aircraft. Mass determinations were made on the right-hand fillet panel.

LEFT-HAND WING-BODY FAIRING

1. A tape patch repair of a deep gouge, first observed in 1980, was still in place, but with one corner torn off (Figure B-1). There was some paint loss near the patch, but no delamination or evidence of damage growth.

2. Another repair, also observed in 1980, in which a 0.3 cm (1/8) in.) crack was filled with resin, was unchanged in appearance.

3. A 1.3 cm (1/2 in.) crack noted in 1980 near the tape patch could not be detected, and may have been only in the paint. An adjacent delaminated area, 0.6 by 1.3 cm (1/4 by 1/2 in.). was detected as before.

4. An area of extensive paint loss along the forward edge was still present, but had not increased in area. This may be indicative of Skydrol.

5. Slight fraying was observed on most fastener holes, but in general this part has less fraying than the other wing-body fairing panels (Figure B-2). The aft and lower edges were slightly more frayed than the forward and upper edges.

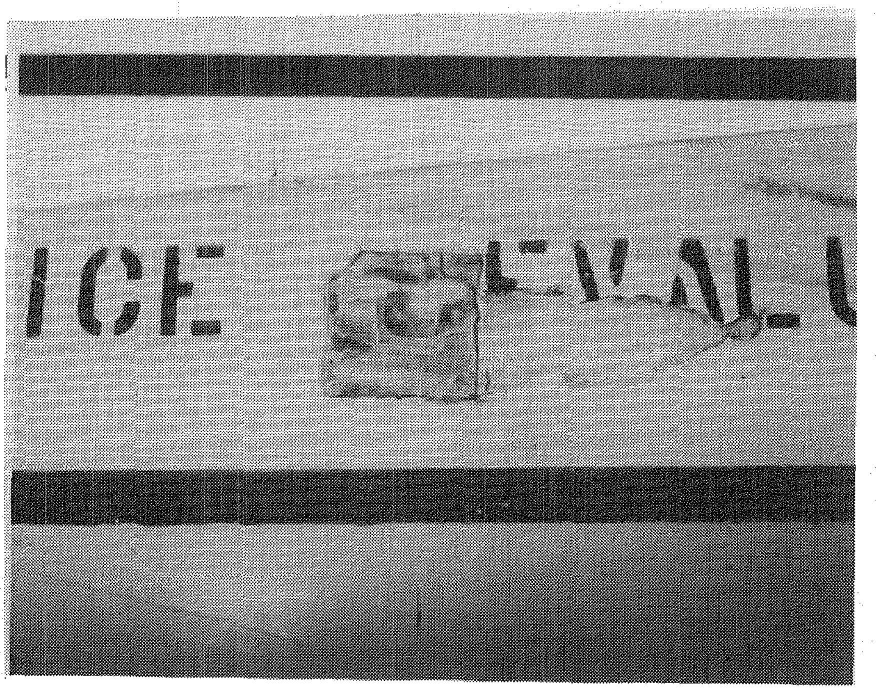

Figure B-1. - TWA Left-Hand Wing-Body Fairing - Tape Patch Repair of Gouge.

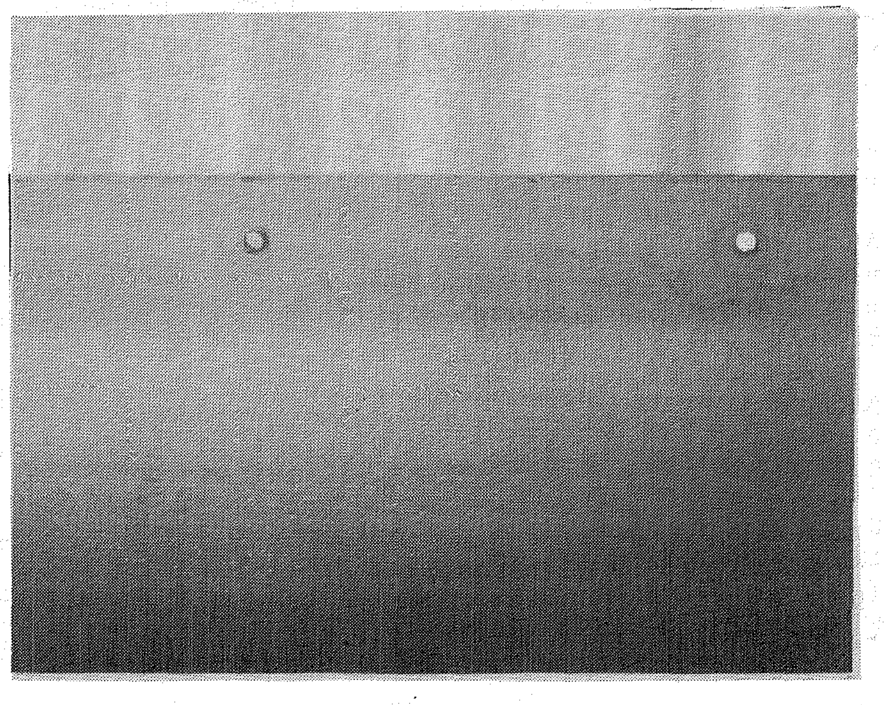

Figure B-2. - TWA Left-Hand Wing-Body Fairing - Typical Fastener Holes with Slight Fraying.

6. Several holes were elongated to a measurable extent: two holes to 0.55 cm (7/32 in.) from the original 0.5 cm (3/16 in.) dimension, two holes to 0.6 cm (1/4 in.), and one hole to 0.7 cm (9/32 in.). These holes also were more frayed than the others.

RIGHT-HAND UNDERWING FILLET

1. The panel mass was 671.0 g (1.479 lb). Previous mass determinations were 664.0 g in the 1980 inspection, 664.6 g in 1979, and 663.75 g in 1978. The increase in mass was probably due to repainting.

2. No surface damage or defects were observed.

3. All of the fastener holes were at least slightly frayed (Figure B-3), and about half the holes were significantly more frayed than the others. Eight holes were elongated to a measurable degree (Figure B-3), six holes to 0.55 cm (7/32 in.) from the original 0.5 cm (3/16 in.), and one hole each elongated to 0.6 cm (1/4 in.) and 0.7 cm (9/32 in.). Five of the elongated holes were among the badly frayed holes, but the two conditions did not correlate exactly.

RIGHT-HAND AFT ENGINE FAIRING

1. There was no damage to either surface. Loss of paint and flame spray had left some exposed Kevlar-49 surface. The vapor barrier coating, which had been applied to the inner surface during reinstallation to replace the Tedlar film, had been chemically attacked in several areas, probably by Skydrol. These conditions had not changed, significantly, since the previous inspection of this part in 1979. There had been some repainting, and an area of the vapor barrier coating near the upper aft corner had become more blackened and flaky.

2. Several holes on the upper edge were slightly frayed, but in general the frayed condition was absent (Figure B-4). All holes on this part had been relocated at the time of reinstallation, and a surface layer of resin impregnated 120 fiberglass fabric had been bonded to both surfaces prior to drilling the relocated holes. This effectively eliminated the fuzziness or frayed condition noted on the other parts.

3. There were a significant number of elongated holes. Ten holes were elongated to 0.55 cm (7/32 in.) from the original 0.5 cm (3/16 in.) diameter; 15 holes were elongated to 0.6 cm (1/4 in.); three holes were elongated to 0.7 cm (9/32 in.) and two holes were elongated to 0.8 cm (5/16 in.). Three intercostal holes were also elongated

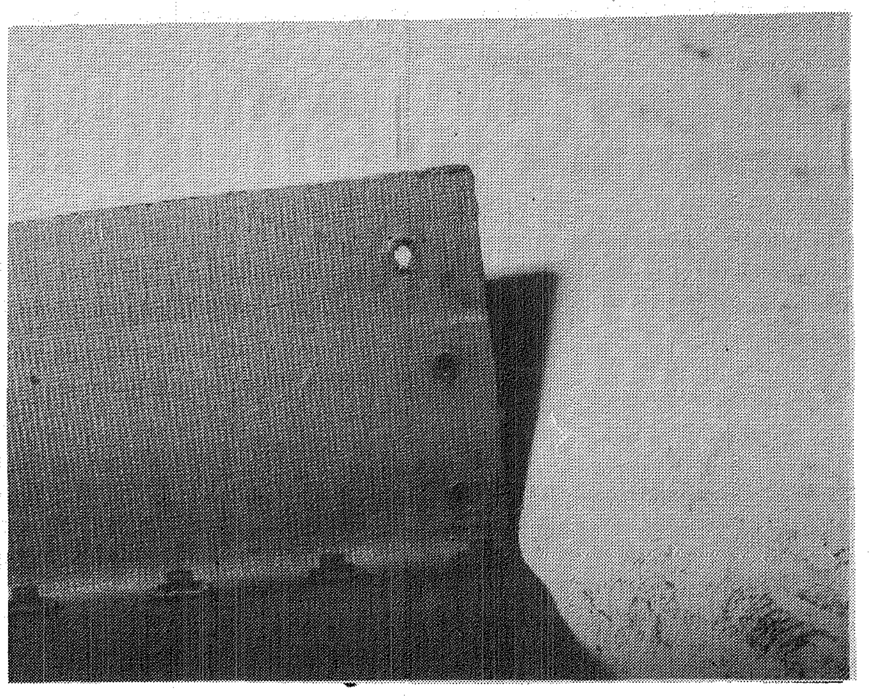

Figure B-3. - TWA Right-Hand Underwing Fillet - Frayed and Elongated Fastener Holes.

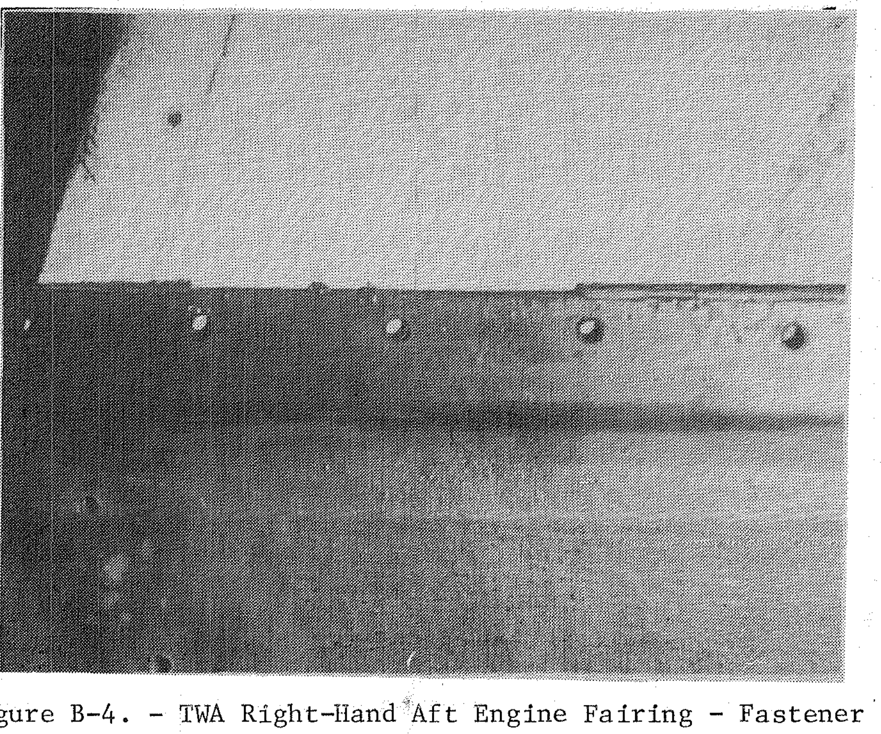

Figure B-4. - TWA Right-Hand Aft Engine Fairing - Fastener Holes Showing Absence of Frayed Condition.

to 0.55 cm (7/32 in.) and one to 0.6 cm (1/4 in.). These elongated holes constituted about 30 percent of the total. Since all holes were relocated, it appears probable that the filled hole areas accounted for the high incidence of elongation.

RIGHT-HAND WING-BODY FAIRING

1. Two new damaged areas were noted: A deep gouge in the upper aft area, about 3.8 cm (1-1/2 in.) in length. There was no associated delamination, and the gouge had been painted over. A smaller gouge was also noted in the upper aft area. This was 0.3 cm (1/8 in.) long and had also been painted over. There was no associated delamination.

2. A large teardrop shaped disbonded and crushed area, 11.4 by 2.5 cm (4.5 by 1 in.) had not changed in size or appearance since the previous inspection. This was first observed in 1977, and is in the lower forward area of the exterior surface (Figure B-5) at the location of a repair. A second disbonded area with a slight associated indentation, 5.1 by 1.9 cm (2 by 0.75 in.) also in the lower forward area of the exterior surface, had increased slightly in area.

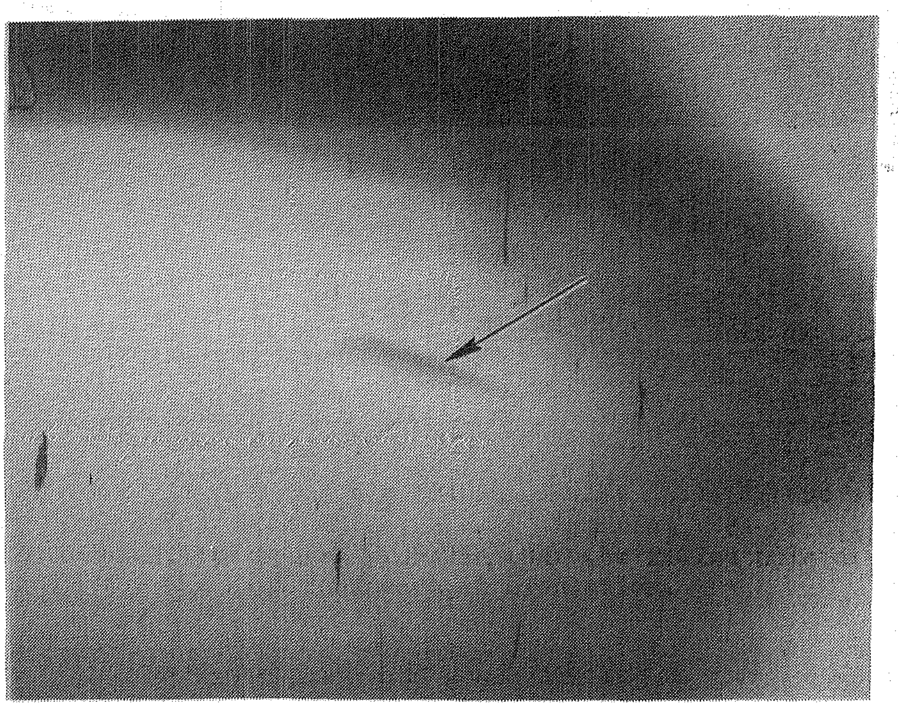

Figure B-5. - TWA Right-Hand Wing-Body Fairing - Disbonded and Crushed Area.

3. A small crack 0.3 cm (1/8 in.) in length on the exterior surface first observed in 1976 could not be detected, and presumably had been filled with resin and repainted since the 1980 inspection. Another crack 0.95 cm (3/8 in.) in length was first noted in 1980 in the lower aft area of the exterior surface. As before it could not be determined whether this crack was in the skin or only in the paint.

4. A rectangular patch overlay 10 by 20 cm (4 by 8 in.) on the lower forward edge of the exterior surface was unchanged in appearance since the previous inspection. This was first observed in 1978, but no damage had been previously observed in that area.

5. A very slight depressed area in the upper aft section, first observed in 1978, was detected. There was no associated delamination or any noticeable increase in size since the initial observation.

LEFT-HAND UNDERWING FILLET

1. Only the lower portion of this part was visible. There were no surface defects or damage. The lower aft edge was slightly bulged, indicating a possible slight misfit of fastener holes.

LEFT-HAND AFT ENGINE FAIRING

1. No observation could be made of this part.

APPENDIX C

DETAIL OBSERVATIONS OF

KEVLAR-49 FAIRING PANELS -

EASTERN SHIP N313EA (SERIAL 1020) -

OCTOBER 1981

Two of the remaining four fairings were removed for inspection: the left-hand wing-body fairing and aft engine fairing panels. The right-hand wing-body fairing was inspected on the aircraft. The two underwing fillet panels were misplaced after their removal from the original aircraft in 1979.

LEFT-HAND WING-BODY FAIRING

1. A deep gouge and associated crack 2.5 cm (1 in.) in length in the upper forward area of the exterior surface was first observed in 1978. A repair consisting of a thixotropic resin filler forming a triangular patch approximately 12.9 cm^2 (2 $in.^2$) in area was observed in 1979. This repair had been painted over but was otherwise unchanged with no evidence of damage growth.

2. A speed tape patch first observed in 1975 had been removed since the 1979 inspection, and presumably the damage had been filled with resin. This was detectable as a slightly depressed line, 7.6 cm (3 in.) long with two delaminated areas at either end, one 0.95 cm (3/8 in.) diameter and the other 0.6 cm (1/4 in.) diameter.

3. A second depressed line was noted in the lower forward area of the exterior surface. This was 8.9 cm (3-1/2 in.) long, and may be the location of a delamination, 3.8 by 2.5 cm (1-1/2 by 1 in.), noted in 1979. This area may have been repaired by a resin filler, and no delamination could be detected.

4. A delaminated area on the inner surface in the upper forward area has been observed since 1975 at which time it was a 1.3 cm (1/2 in.) diameter area with a delaminated strip 15.2 by 1.3 cm (6 by 1/2 in.) extending from it. This area has been noted to increase slightly at the 1977 and 1979 inspections, and in 1981 it was measured as 19.1 cm (7-1/2 in.) in length with a width varying from 3.2 cm (1-1/4 in.) to 1.9 cm (3/4 in.).

5. A second delaminated area was also observed on the upper forward area of the inner surface, 3.2 by 3.5 cm (1-1/4 by 1-3/8 in.) in area. This had not been observed previously.

6. Most of the fastener holes were observed to have at least a slight degree of fraying (Figure C-1). Several holes were noticeably more frayed (Figure C-2) than the others, including two holes in the forward edges and six holes on the lower edge. These fasteners holes had been redrilled upon reinstallation of these fairings in 1979, and several of these holes had a more pronounced fuzziness and frayed appearance than any holes previously observed in this program.

7. Most of the holes showed some degree of elongation. Out of approximately 50 holes on this part, 11 holes were elongated to 0.55 cm. (7/32 in.) from the original 0.5 cm (3/16 in.) dimension; 17 holes were elongated to 0.6 cm (1/4 in.); 9 holes were elongated to 0.7 cm (9/32 in.); and 2 holes were elongated to 0.8 cm (5/16 in.). The elongated areas tended to be areas without the frayed condition, and in most cases it could be seen that the elongation was occurring in the filler (Figure C-3). The filler is a chopped glass fiber filled epoxy resin used to fill the original fastener holes.

LEFT-HAND AFT ENGINE FAIRING

1. No damage or defects were noted on either surface, except for a small depressed area 1.6 cm (5/8 in.) diameter on the lower aft corner of the inner surface. There was no associated delamination. A tape patch was noted on the upper aft corner area of the exterior surface in 1977, and an abraded area was observed at this location in 1979, which presumably was the condition covered by the tape. With repainting of this area this defect is not detectable. There are several areas of paint loss with exposed Kevlar-49.

2. Most of the fastener holes in this part were redrilled through the Kevlar-49 and were fully offset from the filled area (Figure C-4). These holes were all extremely frayed (Figures C-5 and C-6), and the fuzziness and frayed condition was noticeably worse than the holes previously observed on this program. Elongation was noted in about 20 holes (out of a total of approximately 110 holes), and this elongation occurred mainly in areas where the hole was redrilled through a portion of the filled original hole. The elongations ranged from 0.55 cm (7/32 in.) to 0.6 cm (1/4 in.) compared to the original 0.5 cm (3/16 in.) diameter.

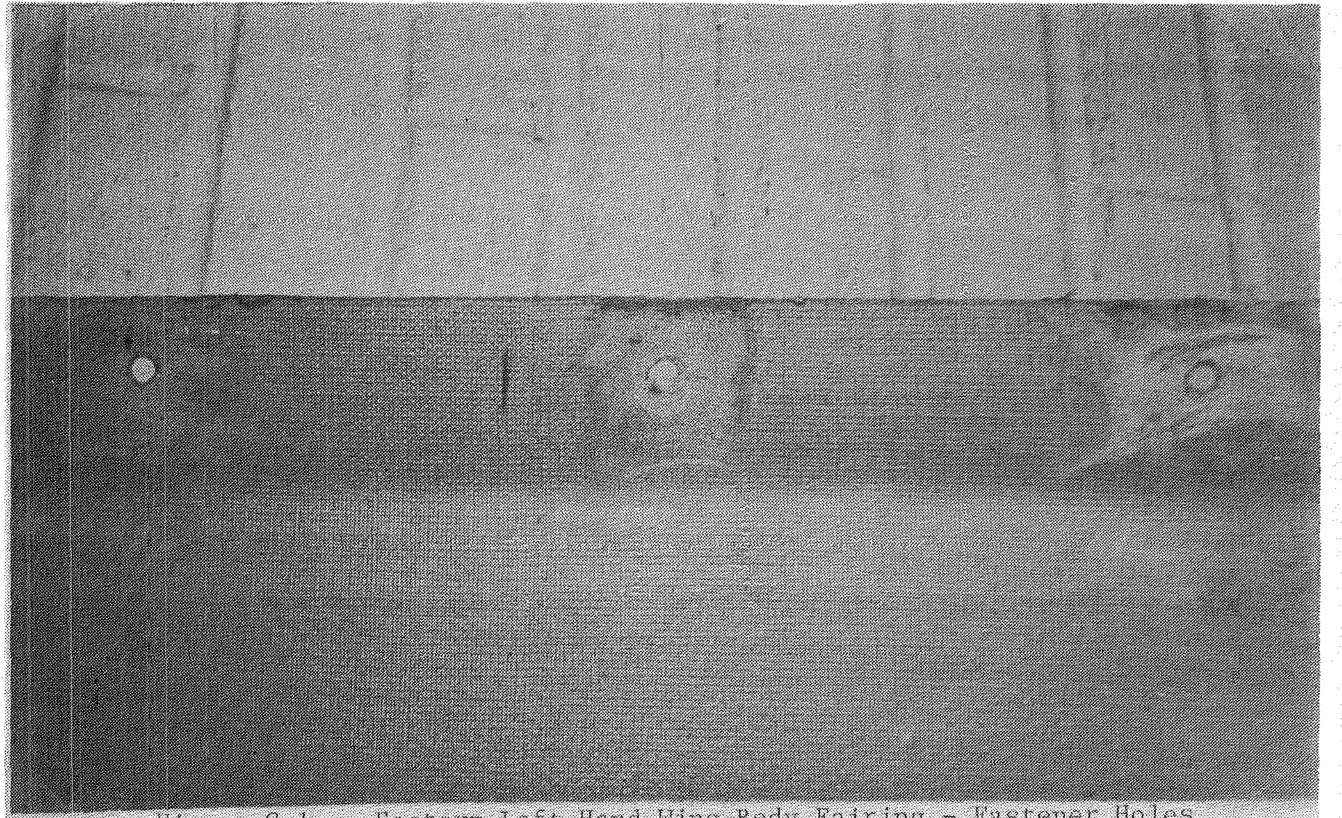

Figure C-1. - Eastern Left-Hand Wing-Body Fairing - Fastener Holes With Slight Fraying.

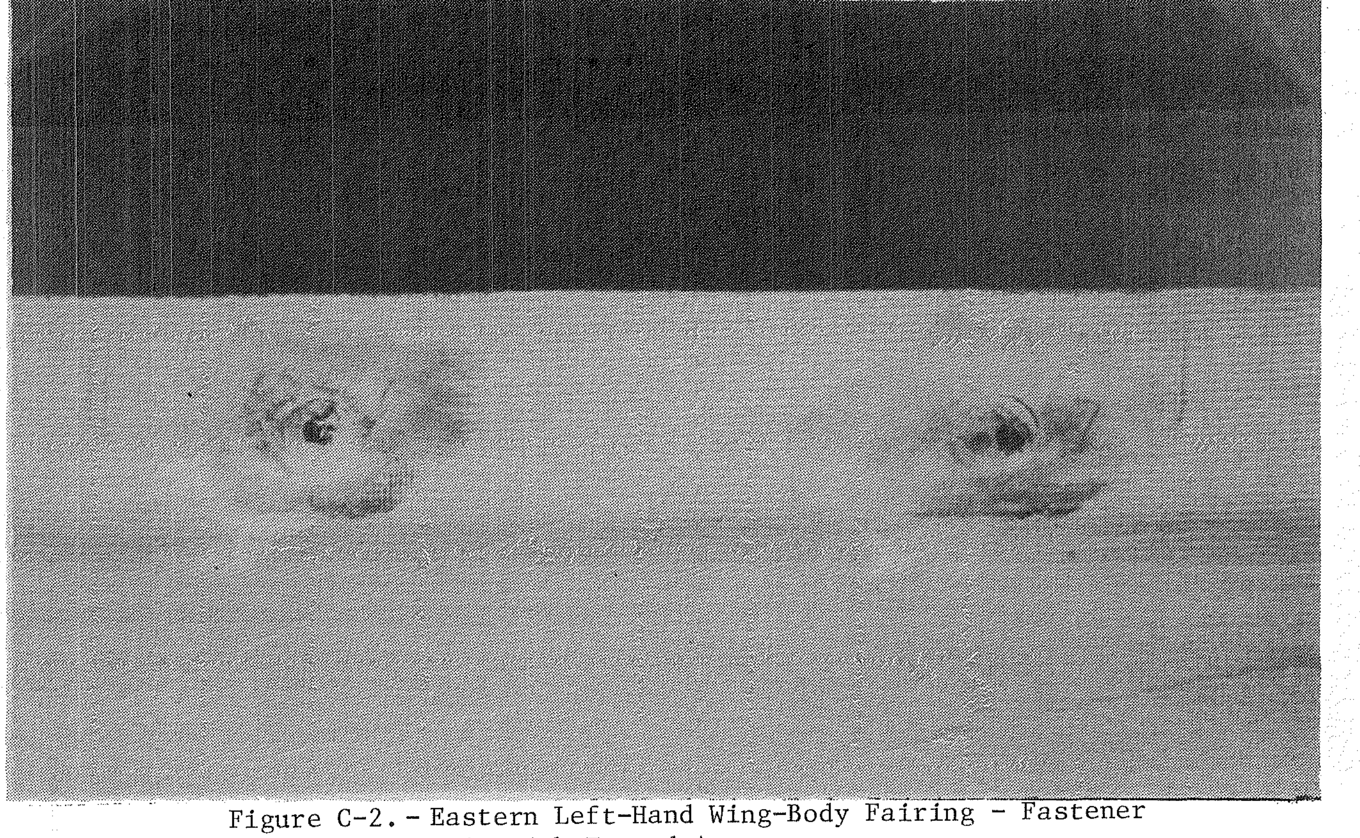

Figure C-2. - Eastern Left-Hand Wing-Body Fairing - Fastener Hole With Frayed Appearance.

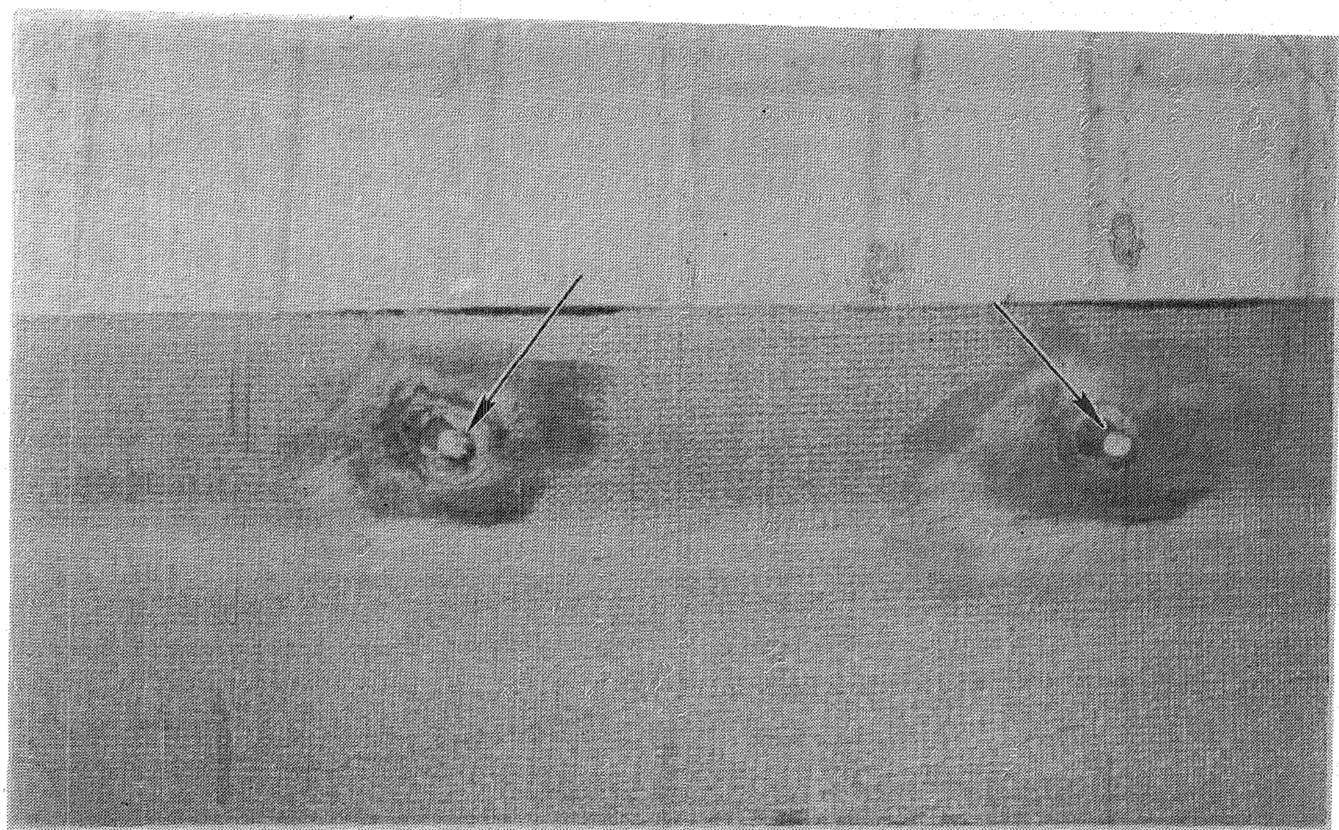

Figure C-3. - Eastern Left-Hand Wing-Body Fairing - Fastener Holes With Fraying in Kevlar-49 Area and Elongation in Filler.

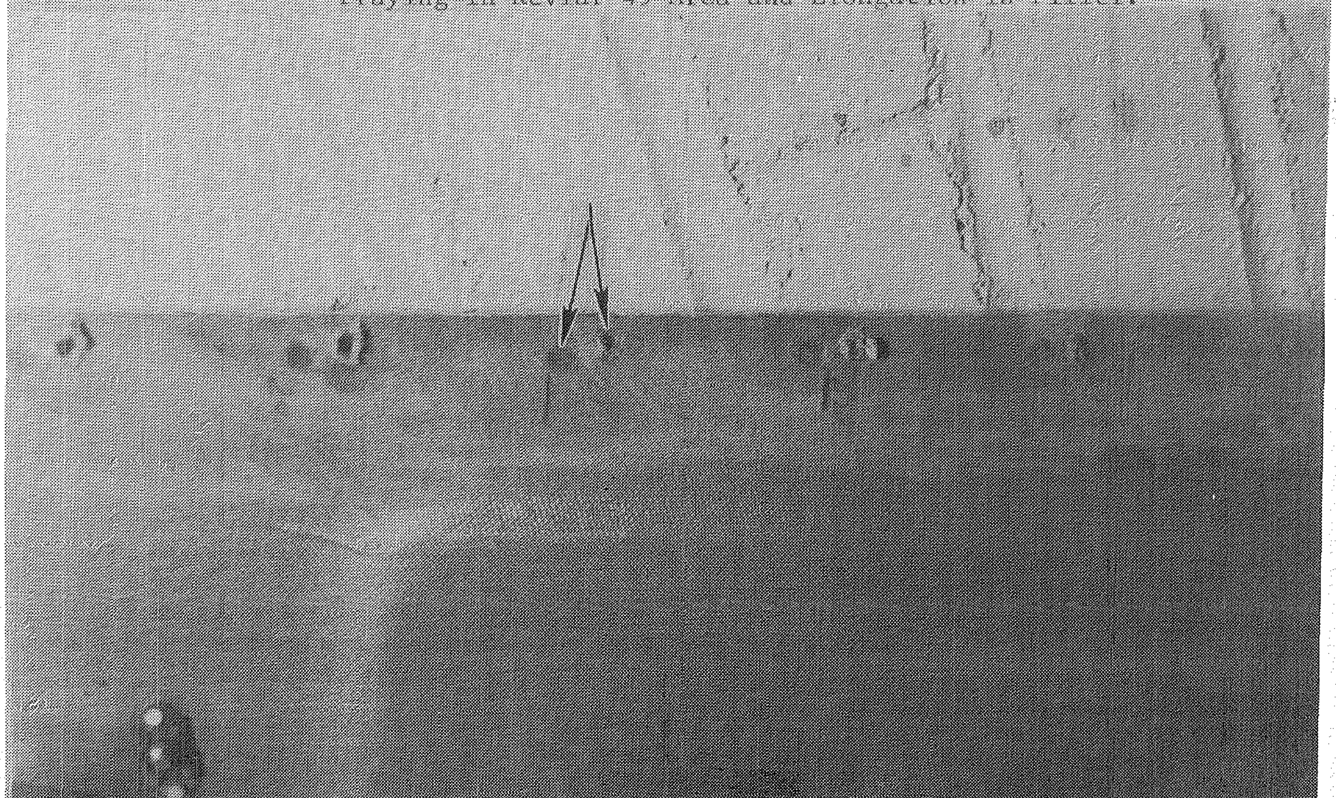

Figure C-4. - Eastern Left-Hand Aft Engine Fairing - Frayed Fastener Holes Showing Offset From Filled Areas.

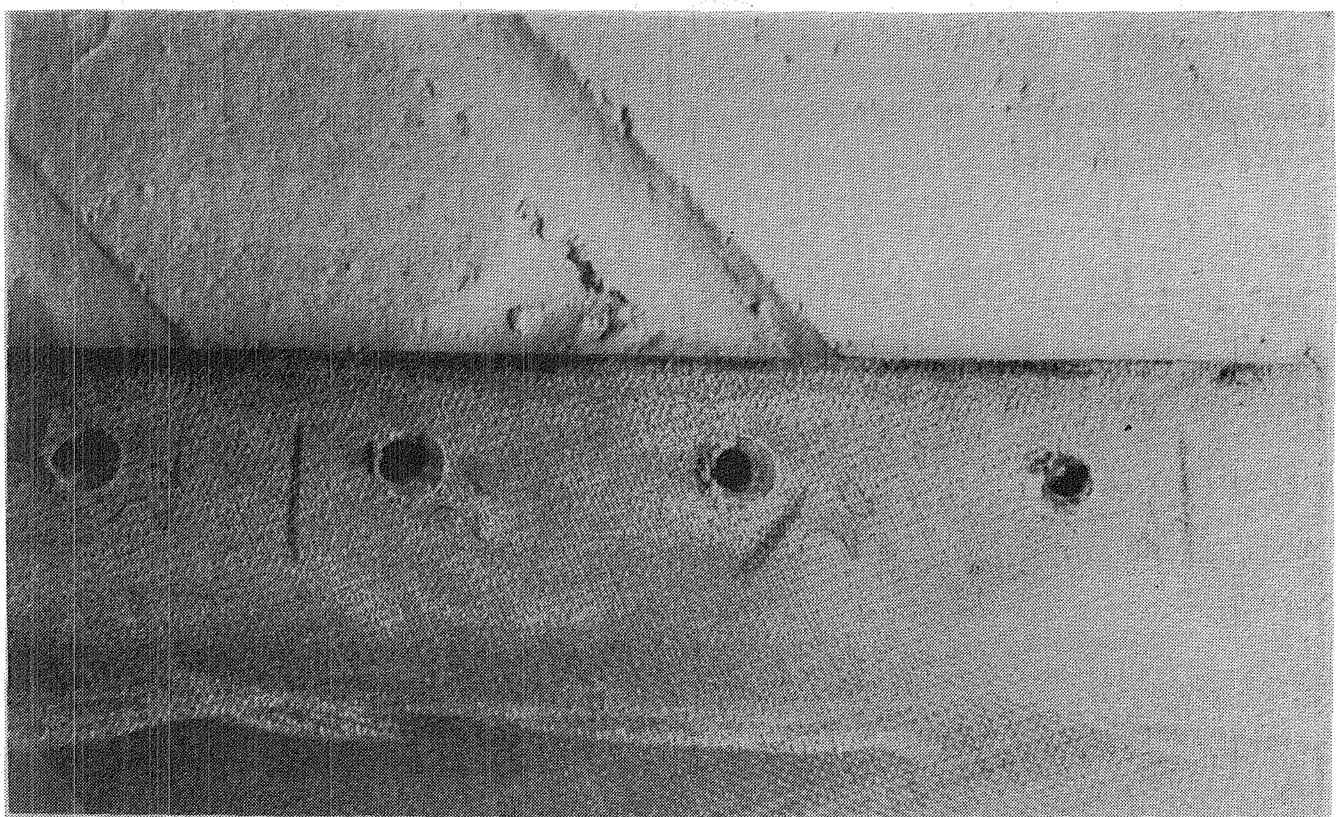

Figure C-5. - Eastern Left-Hand Aft Engine Fairing - Frayed Fastener Holes Along Edge.

Figure C-6. - Eastern Left-Hand Aft Engine Fairing - Frayed Fastener Holes Along Intercostal.

RIGHT-HAND WING-BODY FAIRING

1. Several exterior surface cracks observed in previous inspections had not propagated or changed in appearance:

   - A 1.3 cm (1/2 in.) crack in the forward edge between the fifth and sixth holes from the top.

   - A 0.3 cm (1/8 in.) ding in the lower center area.

   - A 0.3 cm (1/8 in.) crack in the aft center area.

   - A 0.6 cm (1/4 in.) crack in the center area.

2. A 0.8 cm (5/16 in.) crack in the upper forward area of the exterior surface, observed in 1979, could not be detected. This crack was presumably only in the paint. Another 0.8 cm (5/16 in.) crack in the lower forward area of the exterior surface was now detectable (after repainting) as a delaminated or disbond area 0.95 by 1.3 cm (3/8 by 1/2 in.).

3. Two new disbond areas were noted on the exterior surface: an area 2.5 by 1.6 cm (1 by 5/8 in.) in the upper aft section; and an area 3.5 by 1.6 cm (1-3/8 by 5/8 in.) in the lower forward area.

RIGHT-HAND AFT ENGINE FAIRING

1. This part could not be observed due to lack of access on the aircraft.

REFERENCES

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Robert H. Stone

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Annual Flight Service Report. Technical Monitor, Benson Dexter, Materials Division, NASA/Langley Research Center, Hampton, Virginia

16 Abstract Kevlar-49 fairing panels, installed as flight service components on three L-1011s, were inspected after 8 years' service. There are six Kevlar-49 panels on each aircraft: a left-hand and right-hand set of a wing-body sandwich fairing; a solid laminate under-wing fillet panel; and a 422 K (300°F) service aft engine fairing. The three L-1011s include one each in service with Eastern, Air Canada, and TWA. The fairings have accumulated a total of 62,000 hours, with one ship set having 20,850 hours service. The inspections were conducted at the airlines' major maintenance bases with the participation of Lockheed Engineering.

The Kevlar-49 components were found to be performing satisfactorily in service with no major problems, or any condition requiring corrective action. The only defects noted were minor impact damage, a few minor disbonds and a minor degree of fastener hole fraying and elongation. These are for the most part comparable to damage noted on fiberglass fairings.

The service history to date indicates that Kevlar-49 epoxy composite materials have satisfactory service characteristics for use in aircraft secondary structure.

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